1244.

INFORMATION

ABOUT

LIGHTNING CONDUCTORS

ISSUED BY THE ACADEMY OF SCIENCES OF FRANCE

('INSTRUCTION SUR LES PARATONNERRES ADOPTÉE PAR L'ACADÉMIE DES SCIENCES')

TRANSLATED BY

RICHARD ANDERSON, F.C.S., F.G.S.

MEMBER OF THE SOCIETY OF TELEGRAPH ENGINEERS
ASSOC. INST. C.E.
AUTHOR OF 'LIGHTNING CONDUCTORS; THEIR HISTORY, NATURE
AND MODE OF APPLICATION'

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LONDON
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NEW YORK
446 BROOME STREET
1881

BY THE SAME AUTHOR.

PRICE SIXTEEN SHILLINGS,

LIGHTNING CONDUCTORS;

THEIR HISTORY, NATURE, AND MODE OF APPLICATION.

Opinions of the Press.

'One of the best treatises on the subject.' TIMES.

'The work is written in a clear and agreeable style, and no pains have been spared in consulting authorities and collecting statistics.' SATURDAY REVIEW.

'The interesting nature of Mr. ANDERSON'S work may be inferred from the fascination of the first anecdote on which we have chanced to light. Nor is it only as a piece of literary workmanship that we have to accord a full measure of praise to this monograph on lightning conductors. The book is one to be commended to the builders of or dwellers in lofty houses, to the Deans of our cathedrals, to the parsons of churches with lofty spires or towers, and to all owners, constructors, or occupiers of buildings which, from their height or situation, are exposed to danger from lightning.' THE ATHENÆUM.

'The book is clearly and sensibly written, and sufficiently illustrated, and is the work of a practical man who thoroughly understands what he is talking about.' THE ACADEMY.

'Mr. ANDERSON deserves the thanks not only of the scientific world but of the public at large for the very excellent and readable volume which he has produced upon the subject of lightning conductors. There are few persons who can lay claim to the amount of practical experience which Mr. ANDERSON brings to bear upon the subject, and still fewer who add to practical experience an extensive and accurate knowledge of all that has been done and written upon the subject upon the Continent, in America, and in this country. . . . The work contains also a list of books relating to the lightning conductor, a list of all the important observations of accidents by lightning, and an excellent and singularly complete bibliography of the whole subject. The illustrations are numerous and good, and are free from the objectionable sensational character which writers on this and kindred topics sometimes tolerate.' NATURE.

'The great practical importance of lightning conducting has led to the production by Mr. ANDERSON of an elaborate and exhaustive treatise upon the subject, which will help to render available a knowledge of the best means for protecting buildings liable to be injured by atmospheric electricity. Commencing with an account of the early difficulties in electrical investigation and the discovery of lightning conductors, he gives a history of the spread of lightning conductors throughout Europe; then succeeds a chapter on the metals used as conductors, and another on the character of thunderstorms. After this the volume begins to assume a practical character, the best material for conductors is discussed, and the forms and mode of arranging the lightning conductors at the Brussels Hotel de Ville and our own Houses of Parliament are explained. A chapter is devoted to Newall's system of protecting buildings, and an elaborate account given, partly in tabular form, of accidents and fatalities from lightning. The author strongly urges that lightning conductors should be regularly inspected in England as is the rule in continental States. Prefixed to the work is a list of the books consulted in its preparation, and the appendix contains a full bibliography of writings which have more or less bearing upon lightning conductors. The volume is excellently printed and illustrated by woodcuts, showing the mode of connecting lightning conductors with the earth and arranging them on buildings, as well as giving a few illustrations of the kinds of damage done when lightning strikes a building.'

THE WESTMINSTER REVIEW.

'To most folk conductors are a profound mystery, and those who use them, in nine cases out of ten, walk as much by faith and as little by knowledge as did the Dean and Chapter of St. Paul's in 1314, when they set up a new cross on their spire, and in it put "multæ reliquiæ sanctorum ad tuitionem campanilis et totius ædificii sibi subjecti." A work, therefore, which tells us what a lightning conductor should be, and what it should not be, is welcome, even though the counsel it gives for special cases may be summed up in the Abernethyan prescription, "Take advice."' NOTES AND QUERIES.

'Those who do not linger with pleasure over his sprightly, and yet truthful narrative, will not share our taste.' THE BUILDER.

'The volume on "Lightning Conductors," by Mr. ANDERSON, is an example of what is to be gained by the public when men of his class become authors. It embodies his own experience in the construction and planning of conductors, and represents the views of other authorities on the subject.'
THE ARCHITECT.

'The book will, no doubt, become the standard text-book for use by those who are engaged in erecting lightning conductors.' THE BUILDING NEWS.

'The statistics of accidents and list of works on the subject given would of themselves render the book valuable to all who take an interest in the subject.'
ENGINEERING.

'An able and exhaustive work on a subject of vast importance, not merely to professional, but general readers. Mr. ANDERSON has made himself intelligible to both classes, and his work is, in that respect, superior to most books on technical subjects. Then it is written "up to date," which gives it special value, for most other books are, when not written in a dry, unreadable style, somewhat obsolete. Mr. ANDERSON is not contented with merely giving us a history of the invention and development of the lightning conductor, and of the methods that have been devised to make it effective. He gives, in addition, a clear account of the best systems now employed by the leading authorities in various countries.' THE DAILY TELEGRAPH.

'We understand that Mr. ANDERSON has devoted a considerable amount of time during a period of seven years to the accumulation of the material for this work. He has prefixed to the main part of the book the titles of books consulted by him during his labours, and this list seems to exhaust the literature of the subject, giving, as it does, the works by English, French, German, Italian, and Swedish authors. . . . Mr. ANDERSON'S book is not only good, but is the best of its kind, and deserving the careful attention not only of every student, but every householder.' THE ELECTRICIAN.

'A most able and complete monograph, historical, theoretical, and practical, on a subject of great importance and yet generally neglected.'
JOURNAL OF SCIENCE.

'Mr. ANDERSON'S excellent new book will really prove a most valuable addition, not only to a scientific library, but also to the library of every architect or other person concerned in the construction of every kind of building. . . . No good English work, with the exception of the one now before us, has been written. This want has now been supplied, and well supplied too.' THE TELEGRAPHIC JOURNAL.

'Mr. ANDERSON'S book is one which cannot fail to interest readers of every kind, at the same time that it brings together facts which ought to be known to everyone who is responsible for the safety of important buildings. . . . An account of the struggle of ecclesiastical dignitaries against the use of the "heretical rods" will be found in Mr. ANDERSON'S entertaining and instructive pages.' THE PALL MALL GAZETTE.

'It is one of the best works on lightning conductors which we have seen, and, besides being of the greatest practical value, is deeply interesting as a student's work of reference. No one having the charge of property should be without it.' THE COLLIERY GUARDIAN.

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PREFACE.

THE favourable manner in which my book on Lightning Conductors[1] was received by the public and the press induced me to prepare the following translation, intended to be a sort of Appendix to my own work. It is the translation of what may be called a classical pamphlet upon lightning conductors, drawn up by some of the most distinguished men of science who ever investigated the phenomena of electricity.

Alone among the Governments of the nations of the world, that of France undertook, at various periods, to superintend the investigation of the important questions involved in the protection of public as well as private buildings against the terrible effects of lightning. To get the highest information on this subject, various administrations of France in the course of nearly half a century, from 1823 to 1868, addressed themselves to that world-famous scientific body—as high in standing as our own Royal Society—known as 'Académie des Sciences," which appointed, in conformity with the official requests thus made, successive committees, composed of the most eminent electricians of the day. These committees issued, from time to time, their reports upon the subject of lightning conductors. It is an abstract of these reports which I furnish in my translation.

The first report, dated 1823, was drawn up by M. Gay-Lussac. M. Louis Joseph Gay-Lussac, almost more than any other man of his time, made the study of Electricity in the atmosphere, and of meteorology in general, the occupation of his life. Born in 1778, he became at the age of thirty, professor of physical sciences at the celebrated school of the Sorbonne, Paris, and subsequently accepted the place of professor of chemistry at the no less celebrated École Poly-

[1] *Lightning Conductors: their History, Nature, and Mode of Application.* 8vo. 272 pp. London: E. and F. Spon, 1880.

technique. He died in 1850, having been made a peer of France, as a reward for many great discoveries which spread his fame all over Europe. He wrote several works in conjunction with Alexander von Humboldt, the two sharing in public opinion the throne of scientific eminence in the Scientific European world. It may be thought that the report of M. Gay-Lussac, dated April 23, 1823, is now somewhat antiquated, but it is not really so: we still read Aristotle. Besides, as I have had frequent occasion to observe in my book on 'Lightning Conductors,' there has been really very little added to our knowledge of the effect of lightning conductors since the days of Benjamin Franklin. There is scarcely any other instance in history of a discovery like his springing into existence in full panoply, like Minerva from Jupiter's brain.

The second and third reports upon lightning conductors, dated respectively 1854-55, and 1867-68, were drawn up by a 'physicist' scarcely if at all inferior to M. Gay-Lussac—namely, M. Pouillet. The latter, Claude Servais Pouillet, born in 1791, became at a very early age professor of physical sciences at the College Bourbon, Paris, and directed, among others, the scientific studies of the sons of King Louis Philippe. Subsequently, he was nominated Chief Director of the well-known 'Conservatoire des Arts et Métiers' of Paris, the industrial university of France—an university of which we may well envy our neighbours, sadly wanting as it is with us. When in this position, M. Pouillet wrote a book which laid the foundation of his European fame, the work entitled 'Eléments de Physique Expérimentale et de Météorologie.' The work was translated into nearly all the European languages, and was followed by various subjects, such as the electrical tension of the air, marine telegraphs, and the manifestation of thermo-electricity. It was admitted by Professor Pouillet himself that the substance of all his researches about lightning conductors, and the electric phenomena influencing them, were embodied in the two reports laid by him before the Academy of Sciences. As such, these reports, now translated for the first time, possessed an undoubted value.

Shall it be said again and again, that 'they manage things better in France'? As regards lightning conductors, there can be no manner of doubt that they manage things better on the other side of the Channel than with us. It will be seen from the following pages, the French Government are in the constant habit of consulting the most eminent scientific men, as represented in the 'Académie des Sciences,' on the subject of protecting public buildings against the destructive

influences of lightning. There is scarcely an instance in which a British Government did ever such a thing. It is true, the Houses of Parliament had lightning conductors erected upon them, upon some scientific advice, and at certainly very great cost. But all who understand the subject practically agree in saying that it is very doubtful whether the magnificent site of buildings in which our legislators assemble is really, that is efficiently, protected. Certain it is that one-half of our Cathedrals and three-fourths of our Churches have not even nominal protection. For all that science has done, the Queen might any day be killed in her apartments at Windsor Castle, the Prince of Wales in Marlborough House, and the Prime Minister in Downing Street. To see the difference between England and France in this respect, one has but to cross the Channel between Dover and Calais. At Dover there are huge barracks of great length, on the top of high hills, exposed to the full fury of storms sweeping across the Channel; and the few conductors to be found upon them, at long intervals, are certainly not numerous enough for efficient protection against lightning. The contrast in this respect in passing the 'coy silver streak' is of the most striking. At Calais, the 'Hôtel de Ville,' the highest building in the 'Grande Place,' literally bristles with lightning conductors, and so all the churches and other chief buildings in the town. The same all over France. Without slavishly imitating our scientific neighbours, we might yet bestow some of the care they do upon the protection of our property as well as of our lives, against the terrible effects of the electric force.

NOTE.

Since the above was in type the Author has examined and reported on the Con ductors erected on Westminster Palace.

London: Nov. 30, 1880.

INFORMATION ABOUT LIGHTNING CONDUCTORS,

ISSUED BY

THE ACADEMY OF SCIENCES OF FRANCE.

(INSTRUCTION SUR LES PARATONNERRES ADOPTÉE PAR L'ACADÉMIE DES SCIENCES.)

PART I.

The first part of the 'Instruction' was drawn up by a Commission composed of MM. Poisson, Lefèvre-Gineau, Girard, Dulong, Fresnel and Gay-Lussac (the latter acting as reporter), and adopted by the Academy of Sciences, Paris, April 23, 1823.

The accidents caused last year by the destruction from lightning of several churches having determined the Minister of the Interior to carry into effect a project, proposed some time since, of protecting these public buildings by lightning conductors, he has requested the Paris Academy of Sciences to send him an 'Instruction,' the principal aim of which shall be to direct the workmen in the construction and erection of lightning conductors. The Committee known as the Section of Physics has been commissioned by the Academy to prepare this 'Instruction,' which is now submitted for approbation.

In endeavouring to respond as much as possible to the views of the Minister of the Interior, we have thought it necessary to recapitulate briefly the principles upon which the construction of such conductors is founded, not only to enlighten those who will be called upon to inspect the work, but also because these principles are not sufficiently well known, and it is useful to spread them abroad. The 'Instruction' will consist of two parts, the one Theoretical and the other Practical. These two parts will be distinct one from the other, and can be consulted separately.

THEORETICAL PART.

Principles relating to the action of Lightning, or Electric Matter, and of that of Lightning Conductors.

That which is termed Lightning is the sudden passage through the air, in the form of great flashes of light, of electric matter from storm-clouds highly charged with that force.

The velocity of the movements of this electric matter is immense, far surpassing that of a ball at the moment it leaves the cannon, and it is known to be about 1,960 feet per second of time.

The electric matter penetrates bodies, and traverses their substance, but with very unequal velocities.

To those bodies through which it passes with great rapidity, we give the name of *conductors*; such are burnt charcoal, water, vegetation, animals, earth—in consequence of the moisture with which it is impregnated—saline solutions, and, above all, metals, the latter being principal substances which afford very easy passage to the electric force. A cylinder of iron, for example, is a better conductor than an equal cylinder of water saturated with sea salt, in the ratio of at least 100,000 to 1, and this latter conducts a thousand times better than pure water.

The bodies through the substance of which the electric matter forces its way with great difficulty are called *non-conductors* or *insulating bodies*. Such are glass, sulphur, the resins and oils; the earth, stones, and bricks when dry; and all air and gaseous fluids.

Among the conducting bodies there are none, however, which do not oppose *some* resistance to the passage of the electric force; this resistance, being repeated in every portion of the conductor, increases with its length, and may exceed that which would be offered by a worse but shorter conductor. Conductors of small diameter also conduct worse than those of larger diameter.

The electric molecules are mutually repulsive, and consequently tend to separate and disperse themselves through space. They have no affinity for the body of solid matter but only for its surface, where they are retained solely by the pressure of the atmosphere, against which they, in their turn, exert a pressure proportionate at every point to the square of their number. When the latter pressure exceeds the first, the electric matter escapes into the air in an invisible stream, or in the form of a luminous line, commonly called the *electric spark*.

The stratum of electric matter on the surface of a conductor is not of equal density at every point of its surface, except it be a sphere. On an ellipsoid the density is greater at the extremity of the great

axis than on the equator, in the ratio of the great axis to the smaller. At the point of a cone it is infinite. As a rule, on a body of any form, the density of the electric matter, and consequently its pressure on the air, is greater on the sharpest or most curved parts, than on those that are more flat or rounded off.

The electric matter always tends to spread itself over conductors, and to assume in them a state of equilibrium, and becomes divided amongst them in proportion to their form, and principally to their extent of surface. Hence, if a body that is charged with electricity be in communication with the immense surface of the earth, it, *i.e.* the body, will retain no sensible portion of the electric fluid. All that is necessary, therefore, to deprive a conductor of its electricity is to connect it with the moist ground.

Out of several conductors of very unequal powers the electric force will always select the most perfect; but if their differences be small, it will be divided among them in proportion to their capacity for receiving it.

A lightning conductor is simply a path which the electric matter prefers to the surrounding bodies, in order to reach the ground, and expand itself through it. It generally consists of a bar of metal elevated above the building it is intended to protect, and descends, without any breaks or divisions in its length, into water or moist earth. An intimate connection of the conductor with the ground is necessary, in order that it may instantly transmit the electric matter, or lightning, as it receives it, and thus defend the surrounding objects from its attacks. When the lightning strikes the surface of the earth, in consequence of the want of a sufficient conductor, it does not spread over it, but penetrates below it until it meets with a sufficiently large number of channels to carry it completely off. Sometimes it leaves visible traces of its passage, even to a depth of thirty feet. When, also, a conductor is not thoroughly continuous throughout, or is not in perfect connection with a moist soil, the lightning, having struck it, abandons it for some neighbouring body, or divides itself between the two, in order to pass more rapidly into the earth.

An example of the first circumstance occurred some years ago in the environs of Paris. It was effected by an accident which had happened to the conductor of a house—a separation of about twenty-two inches having taken place. The result was that a stroke of lightning, after falling on the terminal rod of the conductor pierced the roof, in order to reach a tin gutter.

Messrs. Rittenhouse and Hopkinson, in volume IV. of the 'American Philosophical Transactions,' report a remarkable example of the second circumstance, or of the danger of not establishing a

perfect connection between the conductor and the soil. The lightning had certainly struck the conductor because it had melted the point very much, and it was evident, after an inspection of the ground, that a portion of the lightning had penetrated by the conductor into the ground; but the other portion of the lightning, not having been able to pass away with sufficient rapidity by the same way, laid waste the roof of the house in order to reach the terminal rod of the conductor upon a copper gutter, the course of which it followed. This gutter was full of water, and consequently offered an easy passage to the soil.

Before the lightning strikes, the storm-cloud by its influence causes all the bodies placed beneath it on the surface of the earth to change their natural conditions. It attracts towards the exterior parts of these bodies the electric matter of a contrary nature to its own, and repulses into the soil that of the same nature. Each body is thus in a state of electric tension, and becomes in its turn a centre of attraction towards which the lightning inclines.

Now because the electric matter developed upon a body by the influence of the electric matter of the tempest cloud comes very rapidly to its maximum, it is indispensable that the conductor be good and in perfect connection with the damp ground.

The electric matter, developed in the bodies on the surface of the earth by the influence of the tempest cloud, accumulates little by little in dimension as the cloud approaches its zenith, and diminishes in the same measure as it becomes distant from them. Suppose a man to be one of these bodies, he would not feel any particular sensation from this progressive variation of electric matter, although having been strongly electrified; but if the cloud discharged instantaneously he may experience—without being struck by the lightning—by the sudden re-entry of his electric matter into the ground, a very acute sensation, which might be sufficiently strong to kill him.

At the moment when any object is ready to be struck by lightning, it is so strongly electrified by the influence of the tempest cloud, if it be in perfect connection with the damp ground, that its electric matter can shoot itself forth towards that of the cloud, and make a part of the path between the cloud and the object. It is this, doubtless, which has induced some persons to think that the lightning, instead of falling from the storm clouds on to the earth, sometimes rises from the earth into the sky. Although this opinion exists, it need not be discussed here, since the efficiency of the conductor would absolutely remain the same in both cases.

A conductor perfectly connected with the ground, and terminating in a very sharp point, instead of being rounded off, may

become so intensely electrified by the influence of the storm cloud, as to give off a continuous stream of electric matter, which is sometimes visible in the dark, appearing as a luminous feather at the extremity of the point; this must certainly tend, in part at least, to neutralise the electrical matter of the storm cloud. A rounded point may exert an equal, or even a greater, attraction on the tempest cloud than a sharp one; but if the flow of electric matter from the points becomes very rapid, the lightning will strike sooner, and from a greater distance between the cloud and the conductor than if its extremity were rounded. At any rate electrical experiments lead to this conclusion.

Thus the most advantageous form that can be given to a conductor appears evidently to be that of a very sharp cone.

Other circumstances being equal, the higher a conductor is elevated in the air, the more its efficiency will be increased.

In the famous experiments of Romas, and in the more recent experiments of Charles, which consisted in raising a paper kite under a storm cloud of a height of from two hundred to three hundred yards, the tail of the kite, in which was twined a metallic wire and which ended in a silken string, led to the surface of the earth so considerable an electric current that it was dangerous and imprudent to expose oneself to it. Now the action of a conductor upon the electric matter of a storm cloud being the same with regard to energy as that of a paper kite, the higher it is raised in the air, the greater its efficiency, not only in protecting the surrounding objects from the lightning, but also in drawing off the electric matter from the storm cloud and neutralising it.

It has not yet been accurately determined how far the sphere of action of a conductor extends: it depends a great deal on circumstances difficult to estimate, but, in several examples, the more remote portions of large buildings, on which they have been erected, have been struck by lightning at the distance of three or four times the length of the terminal rod of the conductor. It is calculated by Charles that a conductor will effectually protect against lightning a circular space whose radius is twice that of the height of the terminal rod; and they are now attached to buildings after that rule.

A current of electricity, whether luminous or not, is always accompanied by heat, the intensity of which depends on the velocity of the current. This heat is sufficient to make a metallic wire red hot, or to fuse it, or even disperse it, if it be thin enough; but it scarcely raises the temperature of a bar of metal, on account of its large mass. It is by the heat of the electric current, as well as by that disengaged from the air, condensed by the passage of the lightning through it when not conveyed by a good conductor, that buildings struck by lightning are frequently set on fire.

No example has yet occurred of an iron bar of rather more than half an inch square section, or of a cylinder of the same diameter, having been fused, or even heated red hot, by lightning. A rod of this size would therefore be sufficient for a conductor, but as its terminal rod must rise from fifteen to thirty feet above the building, it would not be of sufficient strength at the base to resist the action of the wind, unless it were made much thicker at that part.

An iron bar about three-quarters of an inch square is sufficient for the construction of the conductor. It might even be made still smaller, and consist merely of a metallic wire, provided it be connected on the surface of the ground with a bar of metal about half an inch square, immersed in water or in moist soil. The wire, indeed, would pretty certainly be dispersed by the lightning, but it would direct it to the ground and protect the surrounding objects from the stroke. However, it is always better to make the conductor so large as not to be destroyed by the stroke, and the only motive for substituting a wire for a stout bar is the saving in point of expense.

The noise of the thunder generally causes much alarm, although the danger is then past; it is indeed over on the appearance of the lightning, for any one struck by it neither sees the flash, nor hears the clap. The noise is never heard until after the flash, and its distance may be estimated at so many times three hundred and sixty-eight yards as there are seconds between the appearance of the lightning and the sound of the thunder.

Lightning often strikes solitary trees because, rising to a great height and burying their roots deep in the soil, they are veritable conductors. Their shelter is thus often fatal to the unfortunate individuals who seek it: for they do not convey the lightning with sufficient rapidity to the ground, and are worse conductors than men and animals. When the lightning reaches the foot of the tree, it divides itself among the conductors that it finds near it, or strikes some in preference to others, according to circumstances, and sometimes it has been known to kill every animal that had sought refuge under the tree; at other times only one out of many has perished by the stroke.

A conductor, on the contrary, well connected with the ground, presents a certain security against the lightning, which will never leave it to strike a person at its foot. However it would not be prudent to station oneself too close to it, for fear of some accidental break in the conductor, or of its not being perfectly connected with the ground.

When lightning strikes a house it usually falls on the chimneys, either from their being the most elevated parts, or because they are lined with soot, which is a better conductor than dry wood, stone or

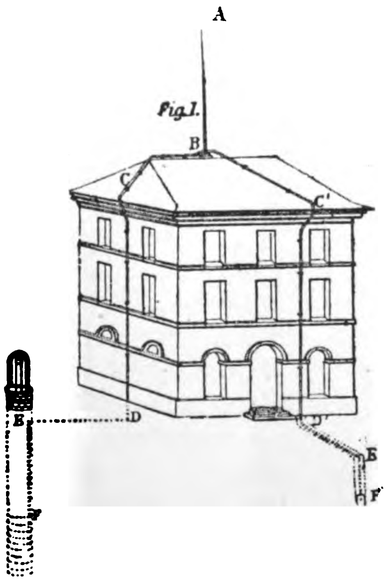
brick. The neighbourhood of the fire-place is consequently the most insecure place in a room during a thunder-storm, when it is safer to station oneself in a corner opposite the windows, at a distance from every article of iron or other metal of any considerable size.

Persons are often struck by lightning without being killed, and others have been wholly saved from injury by silk dresses, which serve to insulate the body, and prevent the access of the electric matter.

PRACTICAL PART.

Details respecting the Construction of Lightning Conductors.

A conductor is a metallic bar, A B C D E F (fig. 1), rising above a building, and descending, without any breaks, to the ground, its



lower end plunging into a well of water or of wet soil. The vertical part B A is called the terminal rod or stem, and projects into the air above the roof, and the part of the bar, B C D E F, which descends from the foot of the terminal rod to the ground, is called the conductor.

The Terminal Rod.

The terminal rod B A is a square bar of metal, tapering from its base to the summit in the form of a pyramid. For a height of from

twenty to thirty feet, which is the mean length of terminal rods placed on large buildings, the base is about two and a half inches square.

The best way of making a pyramidal bar is to weld together pieces of iron end to end, about two feet long each, and of successively decreasing diameters.

Iron being very liable to rust by the action of air and moisture,

Fig. 2.


Fig. 3

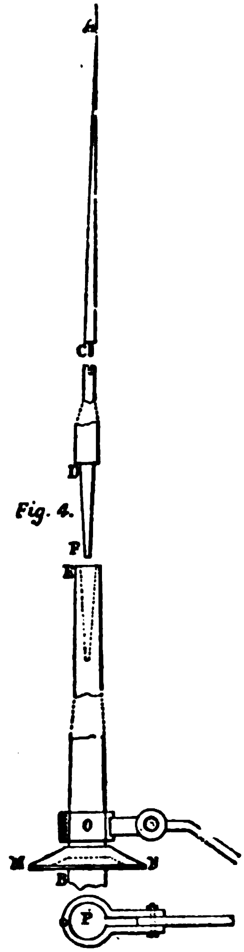


Fig. 4.

the point of the terminal rod would soon become blunt. To prevent this, a portion A H is cut off from the end A B (fig. 2), to the length of about twenty inches, and replaced by a conical stem of brass or copper, gilt at its extremity, or terminated by a small platina needle A G, two inches long. Instead of the platina needle one of standard silver may be employed, composed of nine parts of silver and one of copper. This platina or silver needle is soldered with

silver solder to the copper stem; and to prevent its separating from it, which might sometimes happen notwithstanding the solder, it is secured by a small collar of copper, as shown in fig. 3. The copper stem is united to the terminal rod by means of a gudgeon, which screws into each; the gudgeon is first fixed in the copper stem by two steady pins at right angles to each other, and is then screwed into the iron terminal rod, and secured there also by a steady pin (see C, fig. 4). If the gilding of the point cannot conveniently be performed on the spot, nor the platina readily obtained, they may both be dispensed with, and the plain conical copper stem only be employed. Copper does not deteriorate to any considerable extent in the air, and even if the point becomes somewhat blunted, the conductor will not thereby lose its efficiency.

A terminal rod of the supposed dimensions being somewhat difficult to transport to a distance, it may be cut into two parts, A I, I B, at about one-third or two-fifths of its length from the base (see fig. 2). The upper part, A D (see fig. 4), fits exactly by a pyramidal tenon D F seven or eight inches long, into the lower part E B, and is kept in its place by a pin. The hollow part E D (fig. 4), which receives the pyramidal tenon D F, is made thus:—a strong iron plate is rolled into

Fig. 5.

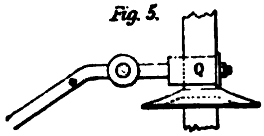
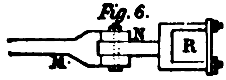


Fig. 6.



a cylinder, and soldered to the bar; then by means of a mandrel of the same form as the tenon, and at successive heats, it is easy to unite its edges and give it, inside and out, the pyramidal shape. It must be mentioned, however, that the terminal rod should always be made of a single piece whenever this is practicable.

Below the terminal rod, three inches from the roof, is a cap (M N, fig. 4), soldered to the body of the terminal rod, and intended to throw off the rainwater which would flow down the terminal rod and prevent its running into the interior of the building, and rotting the rafters. To make this cap, an iron ring is soldered to the terminal rod and drawn out all round on the anvil, inclining the edges so as to form a very flat truncated cone.

Immediately above the cap the terminal rod is rounded for about two inches to receive a split collar, with a hinge O, and two ears, between which the extremity of this part of the conductor is fixed by a bolt. The plan of this collar is seen at P below the terminal rod in fig. 4. Instead of the collar a square stirrup may be made which embraces the terminal rod closely; the vertical projection of this is seen at Q in fig. 5, and the plan at R in fig. 6, as well as the mode

by which it is united to the conductor. Lastly, in order to save labour, we may solder a tenon T, fig. 7, in the place of the collar; but care must be taken not to weaken the terminal rod at this part, where it has to oppose most resistance, and the collar and stirrup are preferable. The terminal rod of the conductor is fixed on the roofs of buildings according to circumstances. If it is to be placed above a rafter, B, figs. 7 and 8, the ridge must be pierced with a hole,

Fig. 7.

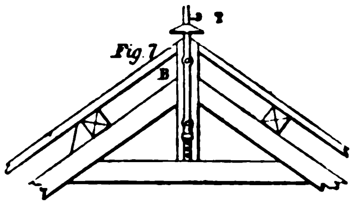
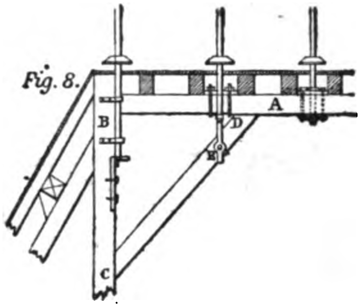


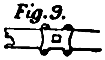
Fig. 8.



through which the foot of the terminal rod passes, and is steadily fixed against the ring-post by means of several bridles as seen in the figure. This arrangement is very solid, and should be preferred if local circumstances permit.

If the terminal rod is to be fixed on the ridge at A, fig. 8, a square hole must be made through it of the same dimensions as the foot of the terminal rod; and above and below we fix, by means of bolts, or two bolted stirrups which embrace and draw the ridge together, two iron plates about three-quarters of an inch thick, each having a hole corresponding to that in the woodwork. The terminal rod rests by means of a small collar on the upper plate, against which it is strongly pressed by a nut, which screws on the end of the terminal rod against the lower plate; fig. 9 shows the plan of one of these plates. But if we can rest against the brace, C D, fig. 8, we should solder two ears to the terminal rod to embrace the upper and lateral faces of the ridge, and descend to the brace, on which they are fixed by means of the bolt, E.

Fig. 9.



Lastly, if the conductor is to be fixed on a vaulted roof, it should be terminated by three or four feet, or spurs, which must be soldered into the stone with lead in the usual manner.

Of the middle and lower parts of the Conductor.

The middle part of the conductor is an iron or metal bar about three-quarters of an inch square, B C D E F, fig. 1, or B′ C′ D′ E′ F′, reaching from the foot of the terminal rod to the ground. It is firmly united

to the terminal rod by being tightly jammed between the two ears of the collar O (fig. 4) by means of a bolt; or it may be terminated by a fork M, fig. 6, which embraces the tail, N, of the stirrup, and the two pieces bolted together.

As the conductor cannot be formed of a single piece, several bars are united end to end. The best method of doing this is shown in fig. 10. The conductor is supported parallel to the roof, at about six inches distance from it, by forked stanchions, which, in order to prevent their letting the rain into the building, are fashioned as follows:—

Fig. 10.

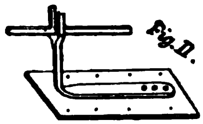


Fig. 11.

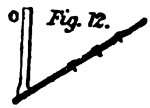


Fig. 12.

Instead of terminating in a point, they have a foot, figs. 11 and 12, formed of a thin plate about ten inches long, and one inch and three-quarters broad, at the extremity of which rises the stanchion making either a right angle with the foot, fig. 11, or an angle equal to that which the roof forms with the zenith, fig. 12. The foot slips in between the slates, but for greater firmness a plate of lead is substituted for the lower slate, and the foot of the stanchion and the lead are nailed down to one of the rafters. The conductor is kept in the forks by pins riveted through them, and the stanchions are placed at about twelve feet distance from one another.

The conductor, after turning over the cornice of the building (see

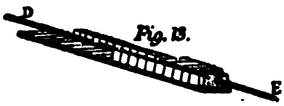


Fig. 13.

Fig. 14.

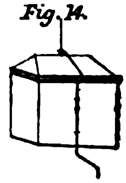


fig. 1) without touching it, is brought into the walls, down which it passes to the ground, and is fixed by means of cramps let into the stone. When it has reached to D or D′ in the ground, about two feet below the surface, it is bent at right angles to the walls in the line D E or D′ E′, and carried in that direction about twelve or fifteen feet, when it turns down into a well, E F, or a hole, E′ F′, about twelve or fifteen feet deep in the ground if no water be met with, but a less depth is sufficient if there be water.

The iron buried in the ground in immediate contact with moist earth will become covered with rust, which, by degrees, penetrates to its

centre, and destroys it. This is prevented by placing the conductor in a trough filled with charcoal, D E, or D′ E′, which is represented on a larger scale at fig. 13. This trough is constructed in the following manner:—

Having made a trench in the soil about two feet deep, a row of bricks is laid on their broad faces, and on them others on edge; a stratum of charcoal or of clean ashes (*braise de boulanger*) is then strewed over the bottom bricks, about two inches thick, on which the conductor is laid, and the trough then filled up with more ashes, and closed by a row of bricks laid along the top. Tiles, stone, or wood, will serve for making the trough as well as bricks. Iron thus buried in charcoal will undergo no change in the course of thirty years. But charcoal not only prevents the iron from rusting, for, being a very good conductor of electricity, after being heated to redness (and that is the reason why we recommend the use of bakers' ashes), it facilitates the passage of the lightning into the ground.

After leaving the trough the conductor passes through the side of the well, and descends into the water to the depth of at least two feet below the lowest water line. The extremity of the conductor usually terminates in two or three branches, to allow a readier passage of the lightning into the water. If the well be situated in the interior of the building, the wall of the latter must be pierced below the surface of the ground, and the conductor passed through it into the well.

If there be no well at hand, a hole must be made in the ground with a six-inch auger to the depth of ten or fifteen feet, and the conductor passed to the bottom of it, placing it carefully in the centre of the hole, which is then to be filled up with coke or ashes rammed down as hard as possible all round the conductor. But if expense be no object, it is better to sink a much wider hole, E′ F′, at least sixteen feet deep (unless water be met with at a less depth), and make the extremity of the conductor terminate in several branches, which must be surrounded by charcoal as before, if not immersed in water, and the conductor itself be similarly surrounded by it, by means of a wooden case filled with the ashes.

In a dry soil, or on a rock, the trench to receive the conductor should be at least twice as long as that in a wet soil, and even longer, if thereby it be possible to reach moist ground. Should the situation not admit of the trench being much increased in length, others, in a transverse direction, must be made as seen at A, fig. 18, in which small bars of iron surrounded by ashes are placed and connected with the conductor. In all cases the extremity of the conductor should terminate in several branches, and pass into a wide hole well filled with the ashes or charcoal that has been ignited.

In general, the trench should be made in the dampest and consequently lowest spot near the building, and the water gutters made to discharge their water over it, so as to keep it always moist. Too great precautions cannot be taken to give the lightning a ready passage into the ground, for it is chiefly on this that the efficacy of a lightning conductor depends.

As iron bars are difficult to bend according to the projections of a building, it has been proposed to substitute metallic ropes in their stead. Fifteen metal wires are twisted together to form one strand,

Fig. 15.

Fig. 16.

and four of these form a rope about an inch in diameter. To prevent its rusting, each strand is well tarred separately, and after they are twisted together, the whole rope is tarred over again with great care. It is attached to the terminal rod of the conductor in the same manner as the bar iron conductor, by means of the collar B (see fig. 15), the ears of which, in this case, are made rather concave, in order better to embrace the rope. Instead of a fork, the stanchions which support it over the roof are terminated by a ring through which the rope passes. At about six feet deep in the ground, it is united

Fig. 17.

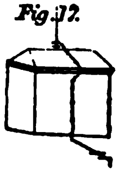
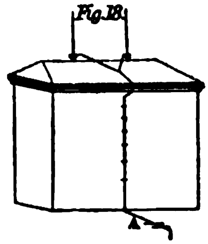


Fig. 18.



to an iron bar, about three-quarters of an inch square, in which the conductor terminates, as seen at C in fig. 16, for the rope would soon be destroyed in the ground. Bars of iron, however, are preferable to the rope; but if, from peculiarity of situation, it be absolutely necessary to adopt them, copper or brass wire is a better material for their construction than iron.

If a building contain any large masses of metal, as sheets of copper or lead on the roof, metal pipes and gutters, iron braces, &c., they must all be connected with the conductor, by iron bars of about

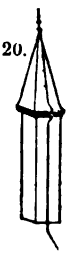
half an inch square, or something less. Without this precaution the lightning may strike from the conductor to the metal (especially if there should be any accidental break in the former), and occasion very serious injury to the building and danger to its inhabitants.

Conductors for Churches.

For a church tower the terminal rod of the conductor should rise from about fifteen to twenty-four feet, according to the area to be protected. The domes of churches, being usually much smaller than the surrounding objects, do not require so high a conductor as buildings with extensive flat roofs. For the latter, therefore, thin terminal rods, rising from three to six feet above the cross or weathercock, will be sufficient, and being light they may easily be fixed to them, without

Fig. 19.

Fig. 20.



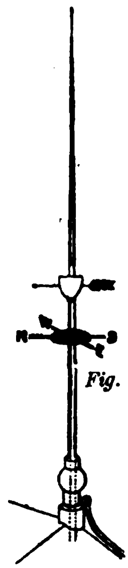


Fig. 21

injuring their appearance, or interfering with the motion of the vane.

When difficult to fix, the terminal rod of a conductor for such buildings may even be omitted altogether, and merely the foot of the cross or weathercock be well connected with the ground. This arrangement requires little expense, and is well adapted for country churches. Fig. 19 represents a steeple without any terminal rod to the conductor, its cross being connected with the ground by means of the conductor which is attached to its foot. Fig. 20 is a steeple with the terminal rod of the conductor fixed to the cross. Churches not protected by a conductor on the steeple require

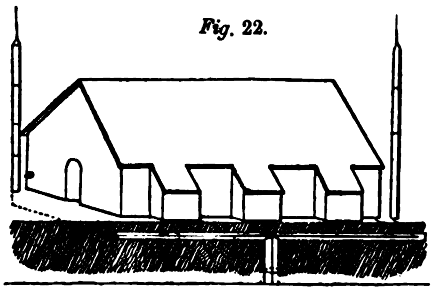
terminal rods from fifteen to twenty-four feet high, similar to those of flat buildings.

Fig. 21 represents a conductor so constructed as to be ornamental, with a vane and similar embellishments.

Conductors for Powder Magazines.

These, of course, require to be constructed with the greatest care, but in principle are perfectly similar to the one we have described at length. They should not be placed on the buildings, but on poles at from six to ten feet distance (see fig. 22). The terminal rods should be about seven feet long, and the poles of such a height that

Fig. 22.



the terminal rod may rise from fifteen to twenty feet above the top of the building. It is also advisable to have several conductors round each magazine. If the magazine be in a tower, or other very lofty building, it may be sufficient to protect it by a double copper

Fig. 23.

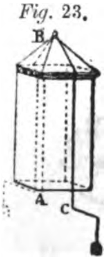
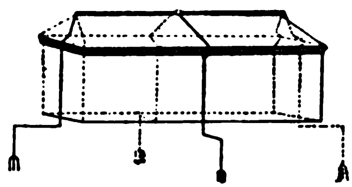


Fig. 24.



conductor (A B C in fig. 23), without any terminal rod. As the influence of this conductor will not extend beyond the building, it cannot attract the lightning from a distance, and yet will protect the magazine, should it be struck. A common magazine, or any other building, may be defended in a similar manner. (See fig. 24.)

Conductors for Ships.

The terminal rod of the conductor of a ship (see fig. 25) consists merely of the copper point, A C (fig. 4), already described. It is screwed on a round iron rod, C B (fig. 26), which enters the extremity, I, of the pole of the top-gallant mast, and carries a vane. An iron bar, M Q, connected with the foot of the round rod, descends down the pole, and is terminated by a crook, or ring, Q, to which the

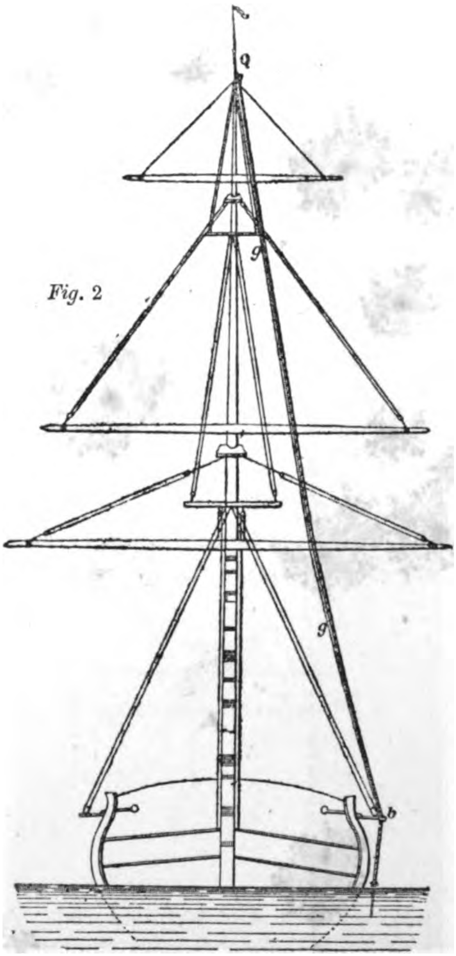


Fig. 2

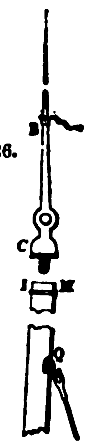


Fig. 26.

main line of the conductor is attached, the latter, in this case, being formed of a metallic rope, and supported at intervals by rigging *g g* (fig. 25), and after having passed through a ring, *b*, fixed to the chains, is united to a bar, or plate of metal, which may be connected to the copper sheathing on the bottom of the vessel. Small vessels require only one conductor; large ships should have one on the mainmast and one on the mizenmast.

General Disposition of Conductors on a Building.

It is known from experiment, that the terminal rod of a conductor effectually protects a circle of which it is the centre, and whose radius is twice its own height, from lightning. According to this rule, a building sixty feet long, or square, requires only a single terminal rod of fifteen or eighteen feet, raised in the centre of the roof (see figs. 14 and 17). In fig. 17 the conductor is a metallic rope.

A building of one hundred and twenty feet, by the same rule, would require a terminal rod of thirty feet, and such are sometimes used; but it is better, instead of one terminal rod of that length, to erect two of fifteen or eighteen feet, one placed at thirty feet from one end of the building, the other at the same distance from the other end, and consequently sixty feet apart from each other (see fig. 18). The same rule should be followed for three, or any greater number of conductors.

For churches with steeples, although the conductor on the latter must from its great height exercise its influence to a consider-

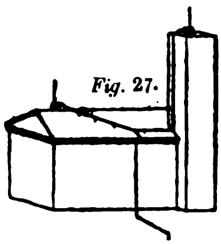


Fig. 27.

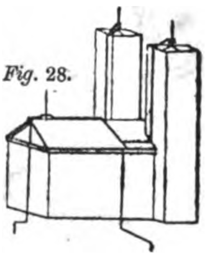


Fig. 28.

able distance, yet as nothing decisive is at present known from experiment as to the greatest distance to which it may extend, it will be prudent to consider it as only protecting a space whose radius is equal to the height of its terminal rod above the ridge of the roof, and to erect other conductors, on the roof itself, according to the rule already given. (See figs. 27 and 28.)

General Disposition as regards Conductors.

Although the necessity of establishing a very intimate communication between the conductor and the soil has already been repeatedly insisted upon, its importance is such that it may be well to revert once more to the subject. If this condition be not rigorously observed, the conductor will not only become much less efficacious, but even dangerous, by attracting the lightning without being able

to convey it to the ground. What other conditions remain to be stated are less important, but nevertheless deserve attention.

The lightning should always be conducted by the shortest possible road from the terminal rod of the conductor to the ground.

In accordance with this principle, when two conductors are placed on a building and terminate in one common rod (which is quite sufficient), the point from which its branches diverge to the two stems, should lie evenly and at equal distances on the roof between them; the common conductor and its branches may be formed of an iron bar, of the same dimensions as for a single conductor. (See figs. 18 and 27.)

If there be three conductors on a building, it will be prudent to give them two special rods (see fig. 28). In general each pair of conductors requires at least one rod.

Whatever number of conductors be placed on a building, they should all be connected together by establishing an intimate communication between the feet of all their terminal rods, by means of

Fig. 29.

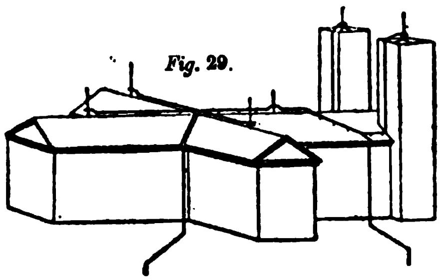
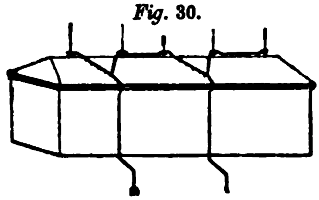


Fig. 30.



iron bars of the same dimensions as those of the conductors. (See figs. 28, 29, 30.)

When the situation will admit of it, the rod or rods should be placed on the wall of the building most exposed to the rain, which, by wetting it, renders it, though imperfectly, a conductor, and if the rod of the conductor be not in intimate communication with the ground, it is possible that the lightning may abandon it for the wet surface of the wall. A further motive for selecting this side of the building is, that the direction of the lightning may be determined by that of the rain, and moreover, the wet surface, being a conductor, may attract the lightning by preference to the conductor.

Observations on the Efficacy of Conductors.

The experience of fifty years demonstrates that when constructed with the requisite care, conductors effectually secure the buildings on which they are placed from being injured by lightning. In the

United States, where thunderstorms are much more frequent and formidable than in Europe, their use has become general; a great number of buildings have been struck, and scarcely two are quoted as not having been saved from the danger. The apprehension of the more frequent fall of lightning on buildings protected by conductors is unfounded, for their influence extends to too small a distance to justify the idea that they determine the lightning of an electric cloud to discharge itself on the spot where they are erected. On the contrary, it appears certain, from observation, that buildings protected by conductors are not more frequently struck than others. Besides, the efficiency of a conductor to attract the lightning more frequently, must also imply that of transmitting it freely to the ground, and hence no mischief can arise as to the safety of the buildings.

We have recommended the use of sharp points for the lightning conductors, as having an advantage over bars rounded at the extremity, by continually pouring off into the air, whilst under the influence of a thunder-cloud, a current of electric matter in an opposite state to that of the cloud: a condition which must have some effect towards neutralising the state of the latter. This advantage must by no means be neglected; for it is sufficient to know the power of points, and the experiments of Charles and Romas with a kite flown under a thunder-cloud, to be convinced that if sharp pointed conductors were placed in considerable numbers on lofty places, they would actually diminish the electric matter of the clouds and the frequency of the fall of lightning on the surface of the earth. However, if the point of a conductor should be blunted by lightning or any other cause, we are not to suppose, because it has lost the property we have mentioned, that it has also become ineffectual to protect the building it is intended to defend. Dr. Rittenhouse relates that, having often examined the points of the conductors in Philadelphia, where they are very frequent, with an excellent telescope, he has observed many whose points have been fused; but that he never found that the houses on which they were erected had been struck by lightning since the fusion of the points.

PART II.

The second part of the Instruction was presented to the Academy of Sciences of France on December 18, 1854, by MM. Becquerel, Babinet, Duhamel, Despretz, Cagniard de Latour and Pouillet (the latter acting as reporter).

In 1823, the Academy of Sciences requested the Section of Physics to prepare a special 'Instruction' upon 'Paratonnerres' or lightning conductors. M. Gay-Lussac was chosen to edit this, and his report very soon received the approbation of the section and that of the Academy itself. Since that time this 'Instruction' has become in some sort a popular manual through the great publicity which has been given to it in all parts. In France, the Government which had ordered this report undertook to introduce it into all parts of the public service, in order that little by little the cathedrals and churches, which are generally more liable than other buildings to accidents from lightning, might be protected more thoroughly. In addition to this, they also wished to see the apparatus applied to powder magazines, arsenals, and all kinds of shipping; in fact, buildings of every sort, including private houses. Abroad these directions, going forth with the approval of the Academy of Sciences, were received with respect and confidence.

It is about a century since lightning conductors were first tried, but even now their efficiency is not unanimously admitted. The ignorant cannot believe that rods of metal arranged in a particular manner can be capable of averting the power of lightning, and even among the learned a good deal of unbelief exists. Long trials were therefore necessary in order to spread this truth, which at first, with the exception of Franklin and a few physicists, had all the world against it. The scientific disbelievers did not stop at saying that conductors were useless, but found reason for believing, and inducing the public to believe, that they were hurtful—that, far from diverting the lightning, their presence would induce the explosion and render it more disastrous. Thus, instead of reassuring the public mind, they added to the natural terror which lightning inspired.

These objections have not been able to prevent the truth from

coming to light, but they have retarded its development. Although they are very antiquated now, they still have some effect. One meets them from time to time, if not on the path of science itself, yet still in close proximity to it. The 'Instruction' of 1823 has contributed in no small measure to weaken them, not only on account of the authority which the sanction of the Academy has given it, but still more through the practical rules which it gives and explains in so clear and precise a manner that it is impossible to misunderstand them. The workmen themselves, with a little attention, have been able to understand what they were doing, and on this account one had not to fear any of those errors in the placing of conductors which formerly were so frequent and often sufficient to neutralise their efficiency.

During the last thirty-one years the science of electricity has made such strides, both theoretically and practically, that one might believe the teachings given at that time are now out of date, and that we should begin again on a new basis. But Science does not proceed thus; she loves progress and gives proof thereof every day. Yet it is very rare that she has to destroy, for the forces of nature remain faithful to their laws. The action of electricity has not altered, but now we know more about it. In 1823, the discovery of electro-magnetism had only been made three years, and none could foresee the immense results with which it would so soon enrich science. However, in spite of these advances, the 'Instruction sur les Paratonnerres' required no alteration in its essential principles. With regard to the construction of buildings, a new element has appeared which must be considered, namely, the great extent to which metal has taken the place of stone and wood. Our buildings have become in many cases metallic mountains upon which the storm-clouds have infinitely more hold. The 'Palais de l'Industrie,' in the Champs Elysées, is an example. It covers a space of nearly three hectares, upon which stands a pile forty metres high, and from base to summit huge masses of iron and zinc are to be found in all parts. The Company which has undertaken this great building asked the opinion of the Academy of Sciences upon the efficiency of the means used to protect it from the effects of lightning. The Academy desired the Section of Physics to examine into the matter and to report upon it. On this occasion it was found necessary to revise the 'Instruction' of 1823 in order to introduce such modifications as were necessary.

It is only accidentally that the 'Instruction' itself touches upon buildings in the construction of which metal has been employed. The only passage in it which refers to the subject is the following:—

'If the building upon which a conductor is placed contains

pieces of metal of any considerable size, such as plates of lead which cover the ridges and the edges of the roof, metal gutters, or long bars of iron used for the strengthening of the building, it will be necessary to connect all these parts with the conductor, but bars of one-third of an inch square or iron wire of the same diameter will suffice for that purpose. If this is not done and there should be any break in the connection with the conductor, or if the conductor does not freely communicate with the earth, it would be very possible that the lightning should be thrown with great force from the protecting rods upon some part of the metal used in the building. Several accidents have happened in this manner. We have cited an example at the beginning of the "Instruction."'

Such are the directions which were given; and although somewhat wanting in detail they were sufficient for their object. We think, however, that the time has now come for entering more fully into the particulars of this subject.

Formerly in ordinary buildings the use of metal was confined almost entirely to the roofs, the gutters, and the braces of the foundation. It was very rare, in fact exceptional, to meet with either an iron framework, or a roofing of lead, copper, or zinc. Now metal predominates more and more. One finds it everywhere, and, what is still more important, in large surfaces and masses; roofs of metal, frameworks, beams, windows, pillars all of metal, and sometimes even metal walls. Now this attractor of electricity decomposes the storm-clouds a hundred-fold more than those other bodies which were not such good conductors, namely, slate, bricks, stone, wood or plaster—in fact, all the materials formerly used in building. The same objection may be applied to this new system of building as is adduced against the conductor—it attracts the lightning.

This objection to conductors has only the appearance of truth. Although it is correct that they attract the lightning, yet it is also true that, obedient to natural laws, the lightning always strikes in a subdued and tractable manner, and generally without noise or spark, having lost all its original power of destruction. On the contrary, when this objection is raised against those buildings in the construction of which large masses of metal have been used, it is not only feasible but entirely true and founded firmly on established physical laws. These buildings do in fact attract the lightning and render its stroke more disastrous.

Given two buildings, equal in size and form, situated upon the same soil, and placed in the same manner with regard to a storm-cloud, the one composed of stone and wood according to the old fashion, the other of large pieces of metal according to the modern style. If neither of them possessed conductors, and the atmospheric con-

ditions were such that the lightning might explode, it would invariably strike the latter and never the former, which would be protected by its neighbour, the electric force being so much more strongly influenced by metal. The same thing would occur in that case as happens when one presents together, at the same distance and in the same position, a ball of stone or wood and one of metal to the conductors of an electric machine—the latter will always receive the spark as soon as it approaches near enough to explode. Conductors are therefore so much the more indispensable for buildings having large surfaces or masses of metal.

In order to form a clear idea of the cause of buildings being struck by lightning, one must not only take into account the building materials, or even all objects to be found above ground, but must pay due regard to the nature of the soil itself, from the surface to the most profound depths. A dry soil, composed of a thin bed of vegetable earth, under which are found dense formations of dry sand, chalk, or granite, will not attract the lightning, because it is not a conductor of electricity. If it should be struck, it would be accidentally, after rain had saturated the surface. In that case buildings participate to a certain point in the privilege of the soil, provided they are not built after the new system, and do not occupy any considerable space. But if under an arid and dry soil there are to be found, at the depth of several dozens of metres, large metallic beds, great caverns, sheets of water, or only abundant springs, the storm-clouds exercise their action upon these conducting materials, the lightning is attracted, and explodes in breaking through the interval. The dry crust not being an insurmountable obstacle, it can be penetrated, excavated, fused, nearly as easily as a coating of varnish is by an electric spark. Then woe betide the buildings which are built upon its surface; let them be of wood or stone, they are destroyed *unless* they possess a well-placed conductor. If these metallic or damp strata are hidden at very great depths, the danger of explosion is diminished from two causes, for one reason the crust which covers them is more difficult to penetrate, and for the second, the action of the cloud is weakened by the increased distance which it travels. One may quote, as a proof of this, the narrow valleys which are sometimes of great length. The lightning never penetrates there, it may strike the crest of the hills, but there is no example of its having descended to the houses, trees, or streamlets, which are found in the regions below. These incontrovertible facts show to some extent what distance from the clouds it is necessary to be, in order to be sheltered from danger.

It is well to keep in mind that the direction of a discharge of lightning is invariably governed by a uniform law. It never strikes by

chance; its points of departure and points of arrival, whether they be simple or multiple, are always marked by a conformity to the electric tension, and the trail of fire at the moment of the explosion ever goes at once from the one to the other; beginning at the same instant at the two extremities. The grass, bushes, or even trees are too small objects to be its end; if they are struck, it is because they are in its path to the true attraction of conducting elements which are hidden in the earth beneath them, and which receive in full the electric discharge and determine the explosion.

Thus the most exposed places are those which, being the nearest objects to the clouds, are charged with moisture or are otherwise good conductors. For example, trees growing upon the summits of hills are subject to the first condition, and vessels in the middle of the sea to the second, and in the localities which possess sufficient of the one or the other, a mean height can be found at which is received at once the most frequent and the most terrible strokes; for the strokes of the same storm-cloud may be strong or weak according to the size of the conducting body which causes the explosion.

We will quote here some facts which may illustrate these general principles, and at the same time justify the modifications which we propose in the construction of paratonnerres.

On April 19, 1827, the packet-boat called 'New York,' of 520 tons, coming from New York to Liverpool, sustained two shocks from lightning. At the time of the occurrence the vessel was in about thirty-eight degrees of latitude north, and sixty-three degrees longitude west, and consequently about 500 miles from the nearest land.

At the first stroke, not having the conductor fixed, the vessel experienced great damage, as may be judged from the fact that a leaden pipe connecting the 'cabinet de toilette' with the sea was completely fused although it was three inches in diameter and three-quarters of an inch thick.

When the second shock came, the conductor had been put up. It was composed of an iron terminal rod about four feet long and half an inch in diameter to which was attached a chain about 130 feet in length, which ended in the sea. This chain was made of iron wire about a quarter of an inch in diameter, each link being eighteen inches long, finishing in buckles and united at each end by round rings.

At the moment of the second explosion the whole of the vessel was illuminated by a bright light; at the same time the chain was divided in all parts into burning fragments and molten globules; the terminal rod itself was fused for the length of a foot from the point. The molten globules set the bridge on fire in fifty places in spite of a thick coating of hail which covered it, and of the rain, which fell in torrents.

The remainder of the conductor kept its place, with about three inches of the top link of the chain left. The largest fragment of the chain found upon the bridge was not a yard in length and was much blistered, thus showing the action of the lightning stroke.

To this we will add another similar event of more recent date. We still refer to maritime occurrences because they are generally described at the time they happen and are noted with much precision by men who have acquired the habit of minute observation. The following is an extract from an account given by the 'Ministre de la Marine' to the Academy of Sciences:—

On the 13th June 1854, in the Baltic, at seven in the evening, the lightning struck the 'Jupiter,' causing it to separate from the North Sea fleet. The chain conductors were in their places. The one on the mainmast, which had received the shock, hung down the side of the vessel with about seven feet of its length in the sea; on its terminal point was placed a ball about four lbs. in weight. At the moment of the explosion there was visible a bright light. At first the loudness of the report and the volumes of smoke led to the belief that the explosion was caused by the firing of a cannon that had become separated from one of the batteries, but this mistake only lasted a moment. The chain of the conductor had disappeared and general damage was visible everywhere. The stern, the poop, the rigging were covered with fragments of wood, and also the clothes of several of the seamen, three of whom were slightly wounded. This chain, which was about 260 feet long, stretched from the terminal rod to the sea, following at first the direction of the mast and then passing through large copper rings the length of the back-stay of the mainmast. It was composed of three strands, formed in all by sixteen brass wires about one fortieth of an inch in thickness

The lightning had scattered this conductor into thousands of pieces, many of them smaller than pins; however, amongst these tiny fragments were to be found here and there pieces of the chain itself. These were about eight inches long, and were violet-coloured, thus showing the intense heat to which they had been subjected; when first touched they were still very hot.

These two examples are sufficient to show that in some cases a conductor may be struck, but they prove at the same time that it is not absolutely useless, since it receives the discharge, directs its course, and thus averts the stroke which if undirected would prove more injurious.

In conclusion the 'Jupiter' received no damage, whils' a Turkish vessel not far from it, which was also fitted with a conductor—the chain of which, however, did not reach the water—received a similar shock of lightning during the same storm, and was found to have in

its side a hole of about one foot in depth. The hole was just above the copper of the bottom and close to the water line. It resembled such a hole as would be made by a cannon-ball.

However, a conductor, instead of inspiring confidence, causes fears only too natural if, when properly placed and in good condition, there is the smallest probability of its being struck, broken into burning pieces, and thrown far and wide like grape shot or a rain of fire.

The question, therefore, is to find out if such accidents are inevitable, whether they belong essentially to the nature of things, or if they are due only to some errors in the construction or application of the apparatus.

Now all the facts which we have just related, and all the other facts more or less analogous which could be quoted in reference to the phenomena of lightning, leave no doubt upon this point. All the conductors which have been destroyed have been bad and insufficient and wrongly constructed; that is, not in accordance with the principles which theory has deduced from experience. It is not that conductors can be made so that they cannot be struck. They are meant to be struck, but in a manner that really governs the lightning and renders innocuous even the most violent strokes.

Examine, for instance, the apparatus of the 'New York' and the 'Jupiter.'

The conductor of the 'New York' had several flaws in its construction. Its terminal rod was too thin and taper, the conductor was too short by one section; besides, the form of a chain is never admissible. It should be excluded from use in the manufacture of conductors, and for this reason—the links only touch each other imperfectly on account of the changes in the metal produced by oxidation &c., and the dust and dirt which adhere to them, and, even admitting that the surfaces of the points of contact are clean and metallic, they are always too narrow, so that even a weak discharge of lightning concentrated on these points is sufficient to fuse the iron.

The nature of these defects suggests the remedy; only it might be feared that it would be necessary to make the divisions of the terminal rods and the conductors of such dimensions that the establishment of a good conductor would be very difficult and almost impracticable in a great number of cases. These fears seem to be somewhat justified by the first discharge which struck the 'New York,' since it was capable of fusing a leaden pipe which had a metallic section of nearly one foot. But this really proves nothing but what has already been demonstrated in the laboratory, namely, that lead is the worst metal that can be employed in the construction of conductors, because it is too fusible and, comparatively speaking, a very bad conductor of electricity. These laboratory experiments

also show that iron or red copper should be used; then we come to very practicable dimensions and a cost that is not exorbitant. There is no case on record which shows that lightning has ever been able to fuse iron rods of three quarters of an inch in diameter, or of one and a quarter inches square section, and, although red copper is much more fusible than iron, it can be employed in rods of still smaller dimensions, because it ranks with gold, silver, and palladium as among the best conductors of the electric force.

The conductor of the 'Jupiter,' although better erected, had yet a radical error in its construction. Of the terminal rod but little can be said, for want of sufficient details concerning the modifications which the electrical discharge produced in it. It may, however, be mentioned that it was wrung and twisted. With regard to the chain which formed the conductor, the singular phenomena of breakage and projection may be accounted for in the following manner: it was thought at first that the conductor was a section too short and in consequence the electric fluid had been dispersed too near the vessel, as was the case with the conductor of the 'New York.' It may be mentioned here that it has been clearly proved by Van Marum, in 1787, that brass possesses in a peculiar degree the property of being broken into a thousand pieces by the action of electricity. However, the numerous fragments of the chain which have been sent to us, and which we have examined under all aspects, bear simply traces of fusion. Besides, in no case do these marks extend throughout the entire thickness of the chain—all of them being limited to one group of some of the sixteen wires which form it. This circumstance appears to prove that the electric discharge is not propagated equally through all the wires, and that those which it has followed—being insufficient to transmit it—have been the ones to be fused, the others being broken and made volatile by the sharp explosion which always accompanies electric volatilisation. Thus arose the breaking of the conductor into pieces and the projection of fragments several inches in length, which, although hot to the hand, were not hot enough to set on fire the wood and other combustible bodies.

This explanation, however, raises the singular question whether, in a chain made of wires of equal size laid and twisted together, the lightning can choose some wires in preference to the rest; above all, when the whole of the wires collectively are hardly sufficient to give it a free passage.

There can be no hesitation in replying in the affirmative, at any rate under certain conditions. Without doubt, if at the two ends of the link of a chain the wires were first separately plated and then soldered together to form in some degree a metallic cylinder, it

would never happen that either natural or artificial electricity having to circulate through the entire length of the chain would show any preference for one or the other of these equal wires; having become solid they follow the same law, they resist together, they are fused or volatilised. But if this condition is not fulfilled, if at the two extremities, or more generally at the two points of junction with the other conductors, the wires are insulated from one another by dirt or oxidation, if further the chain does not touch the other conductors except through the superficial wires, then an altogether different thing would happen. The wires are no more equal or solid, the electric fluid chooses, or rather takes, those which are in contact with the conductor, and these the tension of the chain brings sometimes to the surface, sometimes to the centre of the cluster of wires. These wires being reduced to a small number become incapable of sustaining the effort, and the entire chain, broken by the explosion, always exhibits the phenomena which were produced on board the 'Jupiter' and which have been so well described by M. Lugeol.

These serious imperfections, of which examples have just been given in the struck conductors of the two vessels, although they differ in some respects, yet are to be traced to the same origin and depend upon the same cause, the insufficiency of size. In the case of the 'New York' this insufficiency of size is very apparent, as an iron wire of only a quarter of an inch thick presents a size nine or ten times too small; in the case of the 'Jupiter' this insufficiency is rather hidden and accidental, because it results from badly-made joints. It is to this last point, above all, that attention must be directed.

The two fundamental rules for the construction of the lightning conductors are:—

I. That they have above all a sufficient size, or thickness of metal.

II. That they should be continuous and without defect from the point of the terminal rod to the common reservoir, i.e. the earth, or water contact. But it must be explained what this continuity ought to be, for it may be understood in two ways: it may be admitted that two pieces of metal which touch one another form sufficient continuity for electricity, and it may be admitted on the contrary that very often this very contact is equivalent to a dissolution of continuity on account of oxidation which is caused by the effects of time and of foreign substances deposited between the surfaces.

The 'Instruction' of 1823, without having adopted the first opinion, does not appear to have sufficiently recommended the second, which in our opinion should be used exclusively in all that relates to lightning conductors.

Doubtless in multiplying all precautions and care, two pieces of

iron could be joined and fastened with a bolt so closely that thorough continuity would really be established: but when the joints have to be multiplied, much is to be feared from negligence in the workman, and there is still the danger arising from oxidation, the intrusion of dirt and foreign matter, and lastly the mechanical defects caused by time and the continual shocks from the lightning. Consequently the following practical rules must be regarded as indispensable.

RULE I.—Reduce as much as possible the number of joints in the entire length of the conductor from the point of the terminal rod to the common reservoir, i.e. the water or earth contact.

RULE II.—Fasten by means of pewter solder all the joints which are necessary either on account of the length or the form of the pieces of which the paratonnerre consists.

This pewter solder, which should always extend over a surface at least of four inches square, must besides be consolidated by screws, bolts, or cylinders.

These precautions are demanded by prudence, and above all must be adopted for buildings in the construction of which much metal has been employed; for buildings that are placed on soil of good conductivity; and lastly for ships, because, as we have seen, there are at sea certain conditions which considerably increase the danger and intensity of the electric force.

RULE III.—A third rule to which also some importance is to be attached is not to diminish so much as is usually done the diameter of the terminal rod of the conductor. The upper end of the terminal rod ought to have a section of at least one inch, and consequently a diameter of two-thirds of an inch. Here should be placed a cylinder about one-third of an inch in diameter, and of the same height; on this should be cut a screw thread, and upon this projecting screw should be placed a cone of platinum of three quarters of an inch in diameter at the base, and an inch and a half in height, the angle of the cone being about thirty degrees. This cone is first hollowed in order to form a screw-nut for the screw, made on the end of the terminal rod, and must then be carefully soldered to the iron with strong solder in order to form one continuous whole with the rest of the conductor.

However great may be the tempest cloud, and however considerable its electrical intensity, it is certain that if it was sufficiently distant from the conductor and it approached slowly, there would be no explosion. The conductor would exercise in an efficient manner its protecting action; without absolutely neutralising the electric power of the cloud, it would reduce it in an enormous proportion, and in this case would not only protect a restricted area

round about it, but would by anticipation have protected in a certain measure all the objects over which the cloud would pass in its ulterior course. It is in order to augment this remarkable protective action, that it is necessary to give to the conductor throughout its length this absolute and metallic continuity which is favourable to it in a great degree. The point of an angle of 30 degrees, which is substituted for the much thinner point which is generally used, does not neutralise this protective action, although it may be less favourable to it when the distance is short, and the intensity weak; but it possesses one indisputable superiority in the incomparably greater resistance which it offers to fusion—a resistance which we judge to be necessary.

In fact, it will be well to put this question: Is it possible for a good conductor to be struck in the same manner as a bad conductor or other terrestrial objects, that is to say, by a flash of lightning or a sudden explosion? Now, to this question nothing is found in known facts to authorise us to give an unqualified denial. We can only say that if this phenomenon occur, it must be produced by the fact of a considerable electric force being developed in the vicinity of the conductor. That is all that can be deduced from the laws of atmospheric electricity, which are still but imperfectly known; and it is not impossible that this condition may sometimes occur, either through the many and various actions which take place among the different clouds, or through those rapid condensations analogous to those which send down torrents of rain and hail, or lastly by other causes, the origin of which our actual ignorance prevents us from discovering.

This phenomenon, we do not doubt, is very rare and exceptional, but it is sufficient that it is not impossible for us to draw from it this practical deduction: that it is indispensable to construct a conductor, not only incapable of being destroyed by lightning, but also incapable of being injured thereby so as to weaken its protecting power.

The very thin and fine point does not fulfil this condition, for it does not need a very sharp stroke to weaken it, or even to weaken the rod that bears it to such an extent that from its weight it is bent in the form of a cross, and if a violent shock should occur, the point and some length, more or less, of the rod will be fused and melted. After such accidents, if the conductor itself has not received any injury, it is true that the paratonnerre is not altogether useless, but it is certain that it has lost all the advantage which was sought for by giving it a point of very acute angle. An apparatus thus weakened remains very useful in receiving other strokes and protecting things around it within a certain radius, but it has become useless

for exercising any preventive power, since the terminal rod is no more than an unformed mass covered by a thick coating of oxide. These two states represent the two extreme opinions which at different periods have been pronounced upon conductors. Before the stroke of lightning it represents the opinion of those who ask exclusively for a preventive action in the conductor; after the stroke it represents the opinion of those who, counting the preventive action for nothing, desire only that the conductor might be struck without hurt. We do not pretend to satisfy everybody, but we have a firm conviction that it is possible so to construct a conductor that it shall resist perfectly the most violent strokes of lightning and shall also possess, after the stroke as well as before it, an efficacious preventive action. Such is the aim of the three practical rules which we are about to give.

For the remainder we return to the 'Instruction' of 1823, for we have discovered no fact which renders it necessary to modify the general rules which there were laid down.

Rule I.—For the section of the conductors it fixes the size for square iron rods at nine-sixteenths of an inch, and for round iron rods the diameter is to be ten-sixteenths of an inch.

Rule II.—For the manner of placing conductors upon the roofs of different buildings.

Rule III.—For the way of making them communicate with the common reservoir, i.e. the earth contact.

After having examined all that belongs to the construction and position of the conductor, the subject which occupies us is not exhausted: there is still a very important and difficult question to be solved; it is the question of knowing how to multiply the conductor, or, in other terms, how large is the area of protection which one may leave to a well-placed conductor. Some old observations appear to have proved beyond doubt the occurrence of lightning strokes on buildings which were distant from the terminal rod an interval equal to three or four times the height of the rod above the level of the building. Consequently at the end of the last century the opinion was generally received that the area of protection had for its radius twice the height of the rod. The 'Instruction' of 1823, having found this practice established, has thought well to adopt it. However, it added some restrictions: for example, with regard to conductors on church clocks, it admits that if they are placed at an elevation of 99 feet above the roofs of churches, that for the roofs the radius of the area of protection is reduced to 99 feet instead of being 198 feet.

It is well to remember that these rules, although they have been used for many years, rest on a very arbitrary basis. This is not said

to condemn them, but only to prevent their having attributed to them a virtue which they are far from possessing. Will it not suffice, in fact, that from time to time they were admitted on tradition and with such confidence that it was thought superfluous to submit them to any check or test? Thus they omitted to make any observations on this particular point which could have been brought forward, and which would have furnished science with documents which are almost entirely wanting.

It is only with these reservations, and for want of sufficiently numerous and certain data, that we admit these generally received rules on the size of the area which a conductor protects around itself. We would add besides, for those who are able to observe the facts recorded, that they are neither general nor absolute; that they depend upon a mass of circumstances and particularly upon the nature of the materials employed in construction. We believe, for example, that the radius of the area of protection is not as great for a building the roofing or summit of which is of metal as that of a building which has only wood, tiles, or slate on the exposed parts. In fact, in this last case, the active portion of the tempest-cloud, although notably more distant from the conductor than from the roof, exerts, nevertheless, a more intense influence upon the conductor; while that in the first case, these two actions ought to be very nearly equal for an equal distance.

In concluding here the elucidation of these general principles, we will profit by the occasion which it gives us to draw attention once again to all that which appertains to the effects of storms and to the necessity of minutely observing them. Every time that a storm occurs either near to, or distant from, dwelling-houses, in the plains or upon the mountains, it is nearly certain that there are important observations to be made upon the phenomena which it exhibits. One knows, it is true, a very great number of examples of people being killed, or of houses being set on fire; one knows also many and diverse instances of metals fused, of timber shattered, of stones, and even of walls, thrown far away, and many other analogous effects; but what is generally wanting is precise measurements relative to distance, dimensions, the position of the object—both of that which was struck, and that which escaped. For it is necessary to know what the lightning spares, as well as what it strikes. It is the work of all observers, but especially of officers in the navy and artillery, of engineers, professors, inventors, and architects, to test these phenomena at the moment they are produced, and to describe them accurately for the benefit of science as well as that of public economy. Such descriptions, when they refer to a stroke of lightning, should as much as possible point out the track of the lightning from its highest to

its lowest point; also they should show by sufficiently numerous horizontal sections the relative positions of all objects in a circle wide enough to take in those which have been struck.

The Academy of Sciences will always receive reports of this kind with great interest.

SPECIAL NOTE ON SHIPS.

Red copper is very superior to iron and brass, which are used too often in the formation of the chain which forms the main line of the conductor. Red copper is less altered by atmospheric agencies, and, above all, it can be employed with a section three times smaller than that of iron or brass. We should advise, then, the exclusive use of chains made of red copper. They should have a square section of three-eighths of an inch; then their weight would be about one pound and three quarters per yard. The wires forming the chain should be twisted in three strands in the ordinary manner.

The terminal rod need only be some two or three feet in length including its point, manufactured as we have directed. Its junction with the chain should be made in the workshop with tin solder; for this purpose there must be made in the terminal rod a hole through which to pass the cable. The cable must have about a foot of its length passed through this hole It must then be twisted back and fastened with the rest. Finally, the hole must be filled with tin solder, with which all the wires will be impregnated, and which will form at the points of entry and exit of the chain a kind of wide hemisphere.

With this arrangement the terminal rod of the conductor cannot be screwed to the summit of the pole which receives it: it will be necessary, therefore, to give it a form which will permit of fastening it firmly with a bolt to its support.

At the lower extremity the chain will be adjusted in a similar manner in a piece of copper of convenient form, and it will be essential that this piece of copper should be put in permanent connection with the sheathing of the ship.

The precaution which is sometimes used to insulate the chain of the chain-wale is useless, and the custom of throwing the chain into the sea at the time of the storm is dangerous; firstly, because it is possible that it may be forgotten; secondly, it is often not sufficient that the chain should communicate with the water of the sea by only eight or twelve square inches of surface.

THE PARIS EXHIBITION BUILDING.

THE buildings of the Exhibition cover a rectangle of three hundred and twenty-five feet in width by eight hundred and twelve feet in length, without counting the pavilions which are outside and at the four fronts. The central gallery is about eighty feet broad, while the rectangular gallery which is adjacent to it and which surrounds it on all sides is only about ninety feet. The principals of the roof of this great iron framework are twenty-six feet from one another; they are bound together by rafters in the form of water-pipes by ties and cross-pieces, and the immense whole is supported by several hundred columns of cast iron, independently of the outer wall.

The plan of construction did not allow of the lightning conductors being more than twenty or twenty-three feet high, or that they should be placed anywhere but on the summits of the principals of the roof. Consequently they were fixed on every third principal, that is to say, seventy-eight feet from one another. Thus the rectangular gallery would have thirty conductors, the central gallery nine or ten; as for the pavilions, they would receive more or less according to their size and their position.

A large general conductor has been established along the whole length of the large leaden gutter which goes round the central gallery, having thus a length of sixteen hundred and twenty-five feet. It has been formed of iron having a square section of about three and a half inches and being metallically continuous. Each part of this continuous line is furnished with an individual conductor which is soldered to the general conductor. Lastly, the general conductor itself is placed in communication with the ground by means of four large shafts which are sunk towards the four angles of the main building, and towards the middle of the sides. These are sufficiently deep to have always one yard of water in them. It is necessary that these wells should be distant from one another; it is equally necessary that the conductors which are struck by lightning should come in contact with the water for a large space, either by being tied together in various ways, or by having soldered to them large and thick pieces of sheet iron, zinc, or copper.

The conductors of the pavilions are united in the same manner to the general conductor and to the nearest of the branch ones which are taken to the shafts.

It ought to be noted that there is about a hundred and thirty feet distance between the bases of the conductors on the central and rectangular galleries, while according to the received rules with regard to the area of protection, the conductors of twenty-three

feet should be only ninety-two feet distant from one another. But these conditions are rendered necessary by the nature of the building, which only allowed, as we have already said, to place conductors at the summits of the principals of the roof. Besides, it appears to us that this excess of distance cannot have any great peril, since at the divisions at the bases of the conductors the roofing, having the form of a horizontal cylinder with a circular base, falls rapidly.

The following observations regarding the new buildings of the Louvre were presented to the Academy of Sciences by a Commission composed of MM. Becquerel, Babinet, Despretz, Cagniard de Latour, Regnault, De Senarmont, Pouillet (the latter acting as reporter), and adopted by the Academy on February 19, 1855.

The Minister of Public Instruction and Fine Arts has written to the Academy to ask for instructions respecting the conductors which should protect the new buildings of the Louvre; the Commission charged with this work has just presented its report for the approbation of the Academy.

The Louvre was the first public building in France upon which a lightning conductor was placed: a member of the old Academy of Sciences, Le Roy, had for some time advised this measure, and at length in 1782 it was adopted. In the course of the following years the Government decided to make greater efforts. In 1783 the Minister for War consulted the Academy of Sciences upon the best means of protecting the powder magazine at Marseilles. The Commission appointed to report on this matter included Franklin, Laplace, Coulomb, Le Roy, and the Abbé Rochon. In 1784 the Minister of Marine sent the Academician Le Roy on an expedition to the seaports Brest, Lorient, and Rochefort, to erect conductors on the principal marine establishments, as well as upon the vessels and frigates which were in the roads at the time. Such was the somewhat tardy start of the Administration in this new path—a path in which it had been anticipated by the greater number of the European States. The fact here mentioned is the more remarkable because thirty years before, in 1752, France had outstripped all the other nations, even America, in those experiments which demonstrate in the most decisive and striking manner the truth of Franklin's conjectures about the nature of lightning.

However, as we just mentioned, the lightning conductors of the Louvre were the first sign which showed that the superior authorities had confidence in the discovery. The erection of these conductors

under the superintendence of Le Roy, was found sufficiently satisfactory to recommend the following year the appointment of the Academy Commission, of which Franklin was a member. Thus the palaces of the Louvre and the Tuileries, and, finally, the additions made to them, have been successfully protected from lightning, without its having been found necessary to make any considerable modifications in the primitive type of 1782.

The new buildings of the Louvre, which are progressing so rapidly, and which are designed to complete in one vast whole the three palaces, consist of two parts: the one on the right, the other on the left, of an observer going from the Louvre towards the great centre of the Arc de Triomphe, the Tuileries, and the Etoile. These two parts are separated by a space of about four hundred and thirty feet—nearly equal to the size of the Court of the Louvre, for they are almost the exterior prolongations of the two sides perpendicular to the colonnade—prolongations which are seven hundred and fifteen feet in length and are face to face. At their extremities they fall back at a right angle, in order to join themselves, the one to the continuation of the Rivoli Gallery, the other to the finished gallery of the river-side. These 'returns' thus form two new façades, each two hundred and twelve feet long, and opposite the Tuileries; the first *vis à vis* to the corner of the pavilion of Marsan, at a distance of seven hundred and ninety feet; the second opposite to the corner of the pavilion of Flora, at a distance of eight hundred and sixty-six feet. The great line of buildings, of which we are about to speak, begins at the old Louvre; thus, at its beginning and by this ancient building, it is joined to the gallery of the river-side; in addition to this it is united there again by two other transverse galleries; the one very near to the old Louvre, and the other cutting into two parts the remaining space as far as the back of the new façade opposite the pavilion of Flora. The grand line of the right is joined in an analogous manner to the continuation of the Gallery of the Rivoli.

In order to form some idea of the extent of these buildings, let us imagine the different parts which constitute them detached, with their respective lengths, and then placed one after another in succession. We should then find they would form a length of about three thousand feet, which would be exactly three times the total length of the palace of the Tuileries.

Such is the group of buildings which had to be protected from the effects of lightning.

A new element, which must before all things attract our attention, is the almost exclusive employment of iron, either in the large framework, or for the beams and joists of all the floors. The roofings are similar to the old ones, with the exception that zinc takes the place of lead in the ridges and gutters.

After having investigated the place, the Commission adopted in a general way the former arrangement of the conductors of the Louvre and the Tuileries, that is, with regard to the height of the terminal rods, the interval between them, and the length of the conductors. But in the questions relating to the form of the points and the metallic continuity of the conductors, the Commission confirmed the rules prescribed in the Supplement approved by the Academy of Sciences at the meeting on December 18, 1854.

As to the communication of the conductors with the common reservoir, that is, the earth contact, we recommend it again—like all our predecessors—as an absolute condition which it is necessary to fulfil, at any cost. We will add two observations on this point which seem to us necessary.

Firstly, in the oldest 'Instruction' upon lightning protection it is said that the conductors ought to communicate with the water of a river, a pond, wells, or at least with damp earth: this rule, very correct in itself, often becomes false in the application which is made of it. Sometimes people imagine that lightning can be extinguished with water in the same way as an ordinary fire, and if water is scarce they get over the difficulty by shutting it up in a well-stopped cistern, in which they plunge the lower end of the conductor, thinking that they have thus satisfied the demands of science. This is a most dangerous error. The conductor should communicate with the real common reservoir, that is to say, with vast sheets of water having a larger area than the tempest clouds. The water itself will become fulminating unless it have a sufficient extent. At other times, in localities where wells are possible but expensive, people profit by the alternative left in the 'Instruction;' in place of making wells they put the conductors in communication with damp earth, but they do not disturb themselves to ascertain whether that earth preserves a sufficient moisture in times of drought, when the tempest-clouds are most to be feared; they do not stay to inquire if this damp stratum is sufficiently extensive to leave no room for danger. We notice, above all, this second error, because it appears to be more common than the first. Considering further that it is very difficult to find out whether a damp soil satisfies all the conditions of security, we do not hesitate to say that this mode of communication with the common reservoir should never be had recourse to; we recommend, in default of rivers or large ponds, that the metal of the lightning conductors be always placed in connection with inexhaustible subterraneous sheets of water by means of large surfaces. This exclusive method presents at the present day fewer inconveniences, since the practice of boring has become more easy and less expensive.

Secondly, under certain circumstances, and above all when the

sheets of water are at some considerable distance below the surface of the soil, we think it is necessary to employ a conductor with two branches, a principal branch which descends to the subterraneous sheet of water, and a secondary branch which, parting from the other on the level ground, is put into communication with the soil itself. Here are the reasons for this arrangement. After great drought the tempest exercises but a very weak power over the soil which is dry and therefore a bad conductor, all the energy of its action is felt by the sheet of water below; it is there, then, that the electric decomposition takes place and the electric force, being attracted, follows the principal branch of the conductor and passes away at its point; the secondary branch has in this case no effect. On the contrary, after a wet summer, when the ground is damp, its superficial bed becomes at once a conductor, then it is that it receives the action of the tempest-cloud and at the same time acts as a screen and prevents the electric influence being felt at the subterranean sheet of water. In such times it is indispensable that the surface of the soil itself should communicate directly with the conductor, for it may very likely happen that it has but indirect communication by means of the subterranean sheet. The secondary branch fulfils this condition, whilst this time the principal branch becomes inactive.

This latter observation hardly applies to the soil of Paris, above all that on the borders of the Seine, where the water of the wells is, without doubt, in good communication with that of the river, and consequently in good communication with the streets when they are soaked with rain.

We think, then, that for the new buildings of the Louvre, one should proceed in the following manner. In each of the courts there must be a well sunk of such a depth that, even in the time of great drought, it would always have water to the depth of a yard in it. A funnel of cast iron from five to six inches in interior diameter, receiving the water through lateral openings, will rise from the bottom of the well almost to the level of the ground; there the conductor, after having been put in electric connection with the inner sides of the funnel by means of a cross piece of iron, will descend through the centre of the funnel in order to reach the bottom of the water. Its adjustment will be such that it can be drawn up and inspected from time to time. A flagstone level with the surface of the ground will cover the openings to the wells.

If it happens that several conductors terminate in the same well, they must be all soldered to a common bar which alone will descend into the water. Then its section will have to be from four to five inches square.

There now remains one last question for us to examine, it is the

question of knowing in what manner the lines of the lightning conductors should be put in communication with the different pieces of metal which enter into the construction of the building. Everywhere, as we have said, the roofs are of iron, but the interior arrangements demand that, according to their destination, certain parts of the building have, to speak correctly, but one floor, while other portions have several storeys, and nearly six floors placed one over the other. Each of these floors must be considered as a great metallic network composed of some strong beams of sheet-iron which cross one another with numerous rafters similar to rails, which in their turn are crossed by a multitude of still smaller iron bars; lastly the interstices of this network are filled with earthenware. In examining the effects on a thunderstorm upon the portions of the building where one finds, for example, six similar networks of iron disposed one above another, it is easy to see that if the roof were one great sheet of unbroken metal it would absorb in itself all the electric action of the storm-cloud, at least with respect to the summits and floors beneath it, forming thus for them a kind of protecting screen. In this case it would be sufficient for the roof to be closely connected with the conductors. But the roof we have to deal with is only metallic in a very small degree; one can say that with the summits it only composes a *network* with large meshes, consequently an insufficient screen, through the top floor might still receive a considerable shock.

After that we advise the following arrangements:—

I. The principal pieces of the floors of all the storeys should be put into communication with the neighbouring conductors.

II. It is very desirable that all the beams of the upper floor should be put in metallic communication with one another by means of a bar bolted to each, and if possible soldered to the pewter which will be itself attached to the conductor.

III. It appears to us probable that according to the arrangement in general, the principals of the roof are in good connection with one another by means of the rafters which are between them, and above all by the edge-piece. Consequently it will suffice for the terminal rods of all the conductors to be connected with them. However, if it should happen, either by the change in the level of the roof, or for any other reason, that the connection is doubtful, then it will be necessary to supply special terminal rods.

IV. The zinc pipes and roofs must be metallically connected either with the terminal rods, or to the main lines of the conductors. We will remark lastly that the arrangements which have to do with the gutters and floors of the different storeys can be very easily executed, for in the thickness of the walls, there have been

reserved vertical conduits intended for the pipes to carry away the rain-water. These conduits are sufficiently large to receive at the same time the main lines of the conductors, which will have thus the double advantage of being easily inspected and of being put in communication at a short distance with the metallic pieces of the interior.

This Report was approved as already stated, and the Academy of Sciences decided that it should be printed after that which was read at the meeting of December 18, 1854.

The following report respecting the points of lightning conductors was presented by MM. Deleuil, to a Commission composed of MM. Becquerel, Babinet, Despretz, Cagniard de Latour, Regnault, De Senarmont and Pouillet (the latter acting as reporter), and adopted by the Academy of Sciences on March 5, 1855.

The Commission has examined the points of conductors presented by MM. Deleuil, father and son, with great interest. It found the work such as might be expected from these able constructors, leaving nothing to be desired. One of these points is a cone of massive platinum exactly conforming to the directions given in the report of December 18, 1854; the other is a cone similar in form, size, and all exterior appearances, only it is a little more economical because it is made by means of a conical capsule of platinum to be applied with strong solder upon the conical extremity of the iron terminal rod. Both of these points are three quarters of an inch in diameter and one and a half inches in height. We think that the second arrangement—that is, the capsule or hollow point—need not be inferior in use to the first; but it is necessary that it should be constructed by a clever workman who knows that, in order to be successful, the whole of the interior of the capsule point must take the solder, in order that its entire interior surface may be very closely united to the iron of the terminal rod.

We add that we do not see any inconvenience in substituting palladium for platinum as well as gold and silver of the standard 950 (French), either as a massive cone, or as a conical capsule of a sufficient thickness; and we do not doubt but that in the workshop of MM. Deleuil these other points are constructed with the same perfection as the platinum points presented to the Academy.

However, all these metals are so expensive that very few workmen have much experience in manipulating them, or at least of carrying out this work with that precision and delicate care which are here an

indispensable condition of success. These reasons have led us to make a proposition which had already been discussed privately by the first Commission, and which consists in making the points of the lightning conductor simply of red copper.

The cylinder of red copper has a diameter of three quarters of an inch, like the upper part of the terminal rod of the conductor, and is soldered to it to make the elongation. Its length is about eight inches and it terminates above by a cone of from one inch to one and a half inches in height.

Our conclusion with regard to this red copper point is, that it may be employed with nearly the same confidence as those of platinum. If it is feared that it would experience some superficial oxidation or modifications from the action of the atmosphere, these possible inconveniences are more than compensated for by the following advantages :—

1. The red copper which is found in commerce is, with palladium, gold and silver, amongst the best conductors of heat and electricity. The point of the cone of this metal overheats itself much less than the platinum cone under the influence of electric currents, or even strokes of lightning; thus with the form that we have given it, it is very improbable that it will be broken or even very much oxidised.

2. A conductor with a red copper point entails but very moderate expense. It is within the reach not only of a village or parish, but the great majority of proprietors; it can be made anywhere, for there are doubtless but few villages in France in which one cannot find a workman quite capable of making and adjusting all parts of a conductor constructed after this system.

The report having been put to the vote, M. Despretz, member of the Commission, called attention to some relative points on which he had not been able to share the opinion of his colleagues.

'M. Despretz fears that the coating of carbonate, or of any other matter of less conductivity, with which the copper point will get covered more or less according to the locality, might weaken the efficient action of the conductor. This fear causes M. Despretz to disapprove of the proposal to terminate the conductor by a rod of copper.

'He does not think it prudent to abandon the use of the platinum. He wishes the conductors to be terminated by a platinum cone rounded off at the upper part and soldered to the copper or iron with strong solder. It appears to him that the expense ought not to be more than fifty francs (two pounds sterling) for ordinary buildings.

'He thinks also that in all the chief towns of a department, and in the workshops placed under the direction of the Ministers of War

and Marine, there are men quite capable of soldering the platinum with strong solder.'

These observations having been heard, as well as the replies of M. Regnault and M. Pouillet, the report was put to the vote and adopted.

The Academy decided also that this report should be printed with the preceding, in the little volume entitled, 'Instruction sur les Paratonnerres adoptée par l'Académie des Sciences.'

PART III.

THE third part of the 'Instruction,' relating more especially to the protection of powder magazines against lightning, was presented by a Commission composed of MM. Becquerel, Babinet, Duhamel, Fizeau, Edm. Becquerel, Regnault, le Maréchal Vaillant and Pouillet (the latter acting as reporter), and approved by the Academy of Sciences on January 14, 1867.

The Minister of War, in a letter dated October 27, 1866, desired the Academy of Sciences to send him, as promptly as possible, instructions as to the establishment of lightning conductors upon powder magazines, fearing very justly that some of these magazines are not as much protected as they should be.

The Commission upon lightning conductors, composed of MM. Becquerel, Babinet, Duhamel, Fizeau, Edm. Becquerel, Regnault, the Marshal Vaillant, and Pouillet (reporter), hastened to present for the approbation of the Academy the following 'Instruction.'

In order to prepare it, the Commission has consulted very many documents which have been entrusted to it by the Minister of War. It has also specially consulted the printed works of which we here give the titles, because they form in a manner the history of lightning conductors intended for the protection of powder magazines:—

1. Report made to the Academy of Sciences, April 24, 1784, by the following Commission:—Franklin, Le Roy, Coulomb, De Laplace, Abbé Rochon.

2. Report made to the Institute (6 Nivôse VIII.) on December 27, 1799, by the following Commission:—De Laplace, Coulomb, and Le Roy (reporter).

3. 'Instruction' respecting conductors for powder magazines by the Committee of Fortifications on August 25, 1807.—The general, president, Andréossy; the lieutenant-colonel of the corps; secretary, Alex. Allent; the inspector-general of the corps, Marescot.

4. Report made to the Institute on November 2, 1807.—Commission: De Laplace, Rochon, Charles, Montgolfier, and Gay-Lussac (reporter).

5. Instruction respecting conductors adopted by the Academy

of Sciences on June 23, 1823.—Commission: Poisson, Lefèvre-Gineau, Girard, Dulong, Fresnel, and Gay-Lussac (reporter).

The Commission has also been able to consult some documents collected quite recently by one of its members, M. the Marshal Vaillant, and which refer above all to such powder magazines for which one cannot find any subterranean sheet of water in the immediate neighbourhood.

General Propositions.

1. The tempest clouds which carry the lightning are nothing but ordinary clouds charged with a great quantity of electricity.

The lightning which traverses the sky is an immense electric spark, of which the two points of departure are in two clouds distant from each other and charged with opposing electricities.

The thunder is the noise of the spark in breaking through the air—the crack of a gigantic whip.

The lightning is the spark itself; it is the re-composition of the opposing electricities.

When one of the points of departure of the lightning is on the surface of the ground, one says that the thunder falls, or rather that the lightning falls, and that terrestrial objects are struck. Then all the points of the track of the lightning are again the recomposition, or the neutralisation, of the two opposing electricities, one of which is furnished by the cloud and one by the earth itself.

How does the earth, which is in general in a natural state, and without apparent electricity, find itself thus charged with electricity, and with an electricity adverse to that of the cloud at the very moment it is struck?

Such is the first question that we have to examine.

2. Before the lightning explodes, the tempest cloud which carries it, although at a height of several miles, acts by influence to repulse the electricity of the same kind and to attract the electricity of the opposite. This influence is exercised upon all bodies, but it is not really efficacious except upon good conductors. Such are, in different degrees, metals, water, very damp ground, living bodies, vegetables, and similar matter.

The same conductor experiences very different effects from the cloud, according to its form and dimensions, and, above all, according to its perfect or imperfect communication with the ground.

A tree, for example, when it is in only moderately wet ground, is only influenced in a very small degree, because the similar state of electricity cannot be repulsed to any distance in this ground, which is only a very bad conductor for a great electric charge.

If this tree, on the contrary, was in a soil very damp and of large extent, it would be greatly influenced because the similar state of electricity can spread itself very far in this good conductor. Lastly, it will be influenced as much as possible if this good conductor towards its limits is itself in good communication with other indefinite sheets of water.

When the surface of the earth is acted upon by an electrical machine, that part of it which is visible is called the soil or common reservoir. It is thus called because its conductivity is sufficient to disperse or neutralise this small electric charge.

When, however, it is acted upon by lightning, the surface of the earth is no longer what is called the common reservoir; it becomes, relatively, a bad conductor, on account of the geological formations of different kinds on which it rests. It is necessary to reach the permanent body of water which is to be found at various depths (we will call it the *subterraneous sheet*) in order to find a stratum at which the conductivity is sufficient. This subterranean sheet, on account of its extent and many branches, can never be insulated from neighbouring water-courses, and with them and the rivers and the sea itself, constitutes what is called the common reservoir of tempest clouds, and consequently the reservoir of lightning conductors.

In fact, whilst the tempest cloud exercises, on everything below it, its attractive influence on the opposite state of electricity, and its repulsive influence on the similar state of electricity, it is above all the subterranean sheet which receives the influence with incomparable efficiency. In that case all its upper surface is charged with contrary electricity which the cloud has accumulated there by its attraction, while the similar state of electricity is repulsed and dispersed at a distance in the common reservoir. Also when the lightning explodes, its two points of departure are, the one in the tempest cloud and the other in the subterraneous sheet, which forms, so to speak, the second cloud necessary to the explosion of the lightning.

It is thus that the earth, without ceasing to be in a natural condition as a whole, eventually is rendered electric by the presence of tempest clouds.

Buildings, trees, and living bodies, struck by lightning, should only be considered as mediums which the electric force found in its path and which it struck in passing.

Nevertheless, it is not necessary to conclude that these mediums are essentially passive, and that they never contribute to modify, or even to determine, the direction of the stroke of lightning. On the contrary, it is certain that they exercise, in this respect, an action more or less great according to their extent and good conductivity.

For example, when a vessel is struck in the middle of the sea, it is very probable that the lightning has not taken the route which is *geometrically* the shortest way to the water which it seeks, and where it should be neutralised by the contrary electricity: it is more likely to choose that route which is *electrically* the shortest, on account of the influence the tempest cloud has previously produced upon the masts, rigging, and other conducting bodies of the ship, all of which are more or less elevated above the sea, and more or less conductors.

This phenomenon is analogous to that offered to us by the spark drawn to a great distance by the conductors of a powerful electric machine: it can be turned from its most direct route by the presence of one or several insulated conductors placed near its course; it will come to the same end, but it arrives there by a way electrically shorter, although geometrically longer.

These insulated conductors change in this case the direction of the spark; the mediums of which we have just spoken change the direction of the lightning.

We limit ourselves to the simple announcement of this fundamental principle, which we could not develop here; it contains the explanation of all the movements—sometimes so strange—of strokes of lightning and of all the destructive effects which they produce. A proper account of the phenomena of a stroke of lightning cannot be given without the clear recognition of the two points of departure, and the series of mediums between the two points which have been struck by the stroke of lightning. These mediums are sometimes simple, sometimes multiple.

3. A lightning conductor is a good one if, uninterrupted, its lower extremity communicates extensively with the subterranean sheet, whilst its upper extremity is raised sufficiently high to tower above the edifice which it is to protect.

A discharge from an electric battery will melt several yards' length of not very thick iron wire.

An explosion of lightning can fuse or volatilise a hundred yards' length of bell-wire, or the hammer wires of public clocks. In 1827, on board the packet-boat 'New York,' a chain measuring one hundred and thirty feet in length, made of iron wire a quarter of an inch in diameter, serving as the conductor of the vessel's lightning conductor, was fused by a stroke of lightning and dispersed in innumerable incandescent fragments.

There is no case on record where the lightning has been able to fuse a square bar of iron measuring two yards in length, and having a thickness of about three-fifths of an inch square. This is, therefore, the size of the iron adopted for constructing the main lines of conductors.

It is by no means necessary to look for the subterraneous sheet in a vertical line, or near the vertical line of the edifice that it is wished to protect. A lightning conductor is not less efficient when its line is for a great part of its length in bent curves, either horizontal or oblique. The essential—and absolutely essential—condition is, that the conductor should reach the subterraneous sheet, and that it communicates essentially with it, although it may be necessary to seek this subterraneous sheet at several miles' distance.

4. Let us suppose a conductor constructed under these conditions, and let us examine in a general manner the phenomena which are produced during a storm.

Electricity, developed by the influence of the subterraneous sheet, in place of accumulating there, is attracted to the base of the earth-terminal of the conductor which is the point where it precipitates itself: for in the interior even of a metallic bar, full and solid, and however long it may be, the electric fluid is diffused and propagated with a velocity only comparable to the velocity of lightning itself. It is thus that the electricity attracted by the 'cloud' in the subterraneous sheet becomes suddenly accumulated towards the summit of the conductor.

Thus are the curious phenomena produced, of which it is necessary to give some idea.

If the conductor is terminated at its upper end by as light and very acute point of gold or platinum, the electric force, attracted by the storm cloud, exercises against the air—which is a bad conductor —a pressure sufficiently strong to set itself free, producing a luminous feather, or brush of light, visible in the darkness. The divergent rays of this flash diminish in light according to their distance from the point; they are very seldom visible at a distance of more than six or seven inches from the point. The atmosphere is acutely electrified by them, and there is little doubt but that if the air is calm, these molecules of air, charged with the electric force from the point, are then conveyed to the cloud itself, in order to neutralise a position more or less sensitive to the electric force with which it is charged.

This neutralisation is what is called the preventive action of the lightning conductor.

At the same time that the acute point produces the feather, or brush of light, the flood of electricity which passes through it often acquires such intensity that the terminal rod becomes heated even to fusion. In this case the gold or platinum itself, although much less fusible, falls in voluminous drops along with the copper or iron that support them.

When the terminal rod of a conductor has thus lost its acute

point, and its summit is nothing but a large button of melted gold or platinum, the question must be asked whether it has, or has not, become useless.

To this question we reply: 'No, the conductor is not useless, provided it still continues to fulfil the two essential conditions, namely:—

'1. That the conductor still retains its continuity without break.

'2. That by its lower extremity it communicates largely with the subterranean sheet.'

But in losing its point the conductor has lost somewhat of its preventive action. The aigrette, or brush of light, cannot be reproduced except under much stronger attraction, and the fusion which depends above all on the fineness and acuteness of the point, can only be renovated with difficulty, leaving otherwise, however, things in nearly the same state. The atmosphere is no longer electrified by the aigrette under its luminous form: this part of the preventive action has disappeared. The other part, that which depends on the contact of the upper portions of the terminal rod with the electrified atmosphere, has probably become much less.

For the rest, if it is true that the wind carries away very far from the storm cloud the atmosphere electrified by the aigrette, as well as the atmosphere electrified by the terminal rod, the preventive action is so often reduced to nothing that there is no occasion to regret it much.

The conclusion, then, is that in losing its acute point a conductor is deprived of only a very small advantage.

It is with these motives that the Commission of 1855 has been led to counsel the terminating of the terminal rod of the conductor by a cylinder of red copper, rather more than three-quarters of an inch in diameter, and having a length of from eight to ten inches, the top of which is diminished in order to form a cone of from an inch to one and a half inches in height (*Comptes Rendus de l'Académie des Sciences*, t. xI. p. 522).

This cylinder is adjusted by a screen upon the extremity of the iron terminal rod of the conductor, and soldered to it in order to ensure the continuity of the whole.

In taking now for example a conductor of which the terminal rod is ended by a cone of red copper, and leaving on one side the question of the preventive action, let us continue the examination of the phenomena which are produced during storms.

The cone of copper occasionally exhibits the spectacle of stars, but much more rarely than the acute points of gold or platinum; even in this case it resists the fusion, by reason of its form, and above all by reason of its great conductivity, as much electric as calorific.

If the lightning strikes, it is by the cone of copper that it penetrates the terminal rod and conductor, and it is by this terminal rod of the conductor that it neutralises itself in the subterranean sheet.

The two points of departure of the lightning are, the one on the cloud, the other at the terminal rod of the conductor. There is not in the remainder any luminous or electric appearance throughout the whole surplus of the circuit. The current produced by the lightning passes through the whole extent of the conductor, in the same manner as the current produced by an electric or voltaic battery passes down an iron wire of sufficient diameter.

It is an ordinary stroke of lightning, only it does no injury either to the paratonnerre or the building which the paratonnerre protects; it resembles thus those innumerable strokes of lightning which extinguish themselves in the atmosphere during thunder-storms.

Construction of Lightning Conductors.

The Terminal Rod.—The terminal rod of the lightning conductor is prolonged above, as we have just said, by a cylinder of red copper terminating in a cone; at this point of junction with the copper cylinder it is rounded off and reduced to rather more than three quarters of an inch in diameter; lower down it remains square, and goes on increasing in thickness regularly as far as the insertion of the conductor, where it ought to measure from one and a half to two inches square. Its total height, between the summit of the copper cone and this last joint, may vary between ten and sixteen feet, according to circumstances. There are nearly always greater advantages in augmenting the number of terminal rods, in maintaining them within these limits, and in uniting them by a common conductor, in order to make them continuous, than in reducing the number and giving them a height of from twenty-two to twenty-six feet.

That part of the terminal rod which is below the conductor, or below the lowest of the conductors where there are several, counts no more as a part of the conductor. The form of the terminal rod may be varied at will, and that may be chosen which is most convenient for securing it firmly to its supports.

The Form of Conductors.—The conductor should be secured to the terminal rod by the best pewter solder, and the two should be fastened together by a clamp, which must be connected with them by solder, thus ensuring metallic continuity. All the succeeding lengths of the conductor, excepting those which communicate with the subterraneous sheet of water, should be about five-eighths of an inch square: they must be joined by this means:—the ends of the lengths are laid

side by side and overlapping each other by about six inches. They are then carefully soldered and firmly bolted together with two bolts.

The curves, always rounded, which it will be necessary to give the conductor, either to descend straight into the soil or to extend along the ground to the vertical of the subterraneous sheet of water, will suffice for expansion and contraction.

As it is of importance that these solderings are not weakened by deflections or oblique tractions, it is necessary to establish near them forked iron supports, which, permitting the longitudinal slipping, will restrain all lateral shaking. These supports ought not to be electric insulators.

Communication with Sheets of Water.—The best subterraneous sheet is, as we have said, that of the neighbouring wells which never dry up, and which preserve at least twenty inches depth of water in the most unfavourable seasons.

The well of the conductor should be constructed in the same way as an ordinary well. It ought to be reserved entirely for this service and receive no water from either ditch or sewer.

If circumstances demand it, the ordinary well could be replaced by a boring of from eight to ten inches in diameter, tubed with care in order to prevent the sides from falling in.

That portion of the conductor which descends into the well should be made of iron rather more than three-quarters of an inch square; its lower extremity must carry four 'roots' of about two feet in length, one being bolted to each of the four sides of the descending conductor, and the whole of these joints should be covered with a thick knot of pewter solder. These 'roots' could be replaced by a spiral line of five or six turns, formed by distorting into cork-screw shape the lower extremity of the conductor itself.

The upper part of the vertical portion of the conductor must be fastened to the entrance of the well, either by a sufficiently strong bolt placed upon two parallel bars, or by some other analogous means. These supports should be of such a height that the 'roots' and, if necessary, the knot of pewter solder is always immersed in the water; but it is important that this considerable weight is not placed upon the mud at the bottom of the well, where the 'roots' would sink in.

It is important that there should be contrived some means of ascertaining easily the depth of the water in the well in the different seasons of the year, even when it is possible to discover the movement of these variations of level in the neighbouring wells.

Lastly, it will be necessary to inspect, from time to time, the condition of the immersed iron, for there are certain kinds of water which would be likely to corrode it too greatly in the course of four

or five years. It will be requisite then to undo the last of the solder, which is found outside the well, and, having prepared the suitable mechanical means, to raise the conductor and examine its lower extremity.

Special Arrangements.

The lightning conductors should not be placed upon the building of the powder magazine itself, but outside the gates and the wall of enclosure.

Each magazine of large dimensions (say 290 feet by 60 feet, height 36 feet) must be surrounded by three lightning conductors: two near to the extremities of the large front of the wall of enclosure which is most exposed to the storms, and the third towards the middle of the front opposite. These lightning conductors, of which the terminal rod will be only sixteen feet high, should be raised upon supports forty-nine feet in height, along which the metal will descend to the ground.

A circuit, which we will call the circuit of circumference, because it will follow at a little distance below the soil the exterior of the wall of the magazine, will pass at the foot of the three supports and will be soldered to each of the conductors which descend from the terminal rods. Thus the three conductors are rendered continuous, and it will be sufficient for the electric force to start from the most favourable point of the circuit of circumference in order to seek the subterranean sheet of water.

This arrangement has, above all things, two advantages.

Firstly, it enables all the work of the first erection of the conductors and such repairs to them as are afterwards necessary, to be carried on outside the building, removing thus from the roof and the walls of the magazine those soldering operations which are essential in fitting up the conductors.

Secondly, the circuit of circumference is an addition which guarantees to a considerable extent security from explosions of lightning, which might be accidentally produced under certain circumstances. For example, after heavy rains, when the surface soil is so saturated with moisture that it becomes in some sort, and for some time, the first water sheet.

For magazines of moderate size, two terminal rods and two supports might suffice; for small magazines one terminal rod and one support. But in all cases it is necessary to establish the circuit of circumference.

If it happens that a powder magazine is commanded, or overlooked, at a short distance by mountains, hills, or by lofty buildings, we do not admit that it may be considered as being by these circumstances alone guaranteed from the effects of lightning. On the

contrary, we affirm that it is not the less exposed, and that it ought to be protected in just the same manner as if it had nothing around it which surpassed it in height. In reality, the summits of these hills, or these buildings, could very well, as a rule, receive the first shock of the lightning, but as it is certain that the stroke does not stop there, but prolongs its passage as far as the subterranean sheet, it cannot be asserted that in this long transit it will not take the powder magazine as one of the intermediates it ought to strike.

The powder magazine placed under these circumstances will not then be protected altogether, either against the secondary shock or against the direct shock, unless it is armed by its terminal rods, by its conductors, its circuit of circumference, and its communication with the subterranean sheet.

It remains now for us to enter into some details respecting the constructions which are the consequence of this system.

Supports of the Terminal Rods.—The supports having no electric conditions to fulfil, can be constructed, at will, of stone, bricks, wood, iron, cast iron, &c. They will always be good provided they are forty-nine feet high, are sufficiently solid to resist all winds, and, lastly, if the terminal rod can be fixed to their summit in an unchangeable manner. This may be attained, for example, by three long pieces of wood arranged in a triangular pyramid of which they form the sides, or by corners of iron, or cast iron.

Circuit of Circumference.—The circuit of circumference is composed of three parts, of which one is in nearly a straight line and goes from one end to the other of one of the great fronts of the wall of enclosure; the two other parts are nearly equal to one another in length, and together make up the other three sides of the rectangle. These three parts are united at the same time to each other and to the descending conductors by bolts and pewter solder, by a similar method to that used for joining the lengths of the ordinary conductor, and described before.

For protecting the circuit of circumference different methods may be employed. The trough, or trench, where the subterranean part of the conductor is lodged, can be used, only it must be hollowed out less deeply, and in such a manner that the conductor itself is but little below the soil. It is not necessary to fill the trench with charcoal, earth, or sand. It need not be covered except where the thoroughfare crosses it, and no inconvenience will result if the trench is accidentally filled with water.

In place of the trench, a simple gutter of cast iron may be employed, the sides of which would be level with the ground. In this case at the corners of the wall of enclosure, the angles of the gutter should be joined together by rounded shoulder-pieces. The

gutter also should be covered, sufficiently solid, with wood or stone at the points where the thoroughfare crosses it; everywhere else it should present itself as a water-drain.

Communication with a Sheet of Water.—If the subterranean sheet is at a little distance, the method we have spoken of before must be used. After having chosen in the circuit of circumference the point of departure most favourable for arriving at the well, it is necessary to place there a gutter in the form of a T, which is joined on the right and on the left with the gutter of the circuit of circumference. The end of the branch conductor, which is to be carried to the well, must be bent to an angle and soldered to the conductor of the circuit of circumference. Nothing now remains but to continue the branch conductor, and its gutter, as far as the vertical branch which descends into the well.

If the subterranean sheet is only to be found at a great distance, and in order to get there it is necessary to run over the slopes of hills several hundred yards, or even several miles, the theory does not change in its consequences. For it is imperative that the conductor should descend to the subterraneous sheet, and impossible for it to remain on the way.

One can understand that practical people might be somewhat frightened by such an obligation; however the problem is of so much importance that one ought not to regard it as insoluble before having ascertained the nature of the difficulties which it presents.

Materially, the transit of the conductor only demands an increase of length in order to be prolonged by one or other of the methods just indicated, or by other analogous ones.

In truth, the greater the distance the more chance of meeting with ground difficult to break through, rocks, heaps of rubbish, &c.; in a word, serious obstacles would oppose its continuation level with the ground.

In such a case there would be an advantage in changing the method, and substituting the aerial system for that of the level of the ground. It would suffice for this purpose to introduce some modifications, as in the ordinary arrangement of telegraph wires.

The strongest wires must be taken, those of from a quarter of an inch in diameter. The joining of the ends of the lengths of wire must be performed by means of a cylinder filled with solder. It is necessary that the wires should be plated beforehand, and that the cylinder should have a length of from six to eight inches.

It will be essential to employ six wires in order to obtain a sufficient strength. They should not be united or mingled, but separated one from another.

Instead of being insulated on their poles, or posts, as they ought

to be for the telegraph, they should, on the contrary, be supported by iron brackets or blocks of cast iron, the arrangement of which must vary according to whether the wire is continued in a straight line or a broken one.

Lastly, the junction of the system of the wires with the system of the conductors on the level of the ground must be made by means of bolts and cylinders firmly soldered together to form one continuous mass.

In combining these two systems according to the circumstances and accidents of the ground, it will be possible, without doubt, to surmount all material obstacles.

However, the problem is not completely solved. There remains one difficulty of another nature: for what would these conductors serve if they became the playthings of children, or if they excited the greed of thieves, or the attention of mischievous persons, who could at any moment deface or destroy them?

Everybody understands that it is necessary to erect lightning conductors on powder magazines in order to prevent great disasters. It is not the less necessary that they should be respected throughout the whole extent of their course. Let us add, lastly, that there is room to hope that lightning conductors will not inspire less respect than telegraph wires.

It is known that one coat of paint does not compromise the electrical functions of a conductor. Thus there can be applied to the terminal rod of the conductor such paint or other coating as may be thought most suitable for preserving them. But the immersed part of the conductor must always be excepted from this rule, and remain in immediate communication with the water of the well.

The following notice about the lightning conductors of the Louvre and the Tuileries was drawn up by a Commission composed of MM. Becquerel, Babinet, Duhamel, Fizeau, Edm. Becquerel, le Maréchal Vaillant and Pouillet (the latter acting as reporter), and adopted by the Academy of Sciences on July 20, 1868.

The Minister of the Emperor's household and of Fine Arts sent to the President of the Academy on March 2, 1868, plans and reports upon the lightning conductors of the Louvre and Tuileries, desiring him to consult the Academy of Sciences upon this subject.

The Commission on lightning conductors, of which the Minister is himself a member, hastened to collect all the documents and special facts the knowledge of which was necessary for entering into an

exhaustive examination of the great question proposed to it. The Academy, already consulted in 1855 on the occasion of the new buildings of the Louvre, had given its advice on this particular point (see *ante*). But after the Minister's letter, and after the explanation which it gave to the other members of the Commission, the Academy is now consulted on the whole of the huge mass of buildings which extend from the colonnade of the Louvre as far as the Palace of the Tuileries, and which thus circumscribe an extent of twenty-seven acres. The length of these monumental constructions, old as well as new, is nearly two miles.

The principles approved of by the Academy, either in its 'Instruction' of 1855, or that of 1867, which relates to powder magazines, ought assuredly to serve as a guide in these extraordinary circumstances as well as in the most common cases. The present Commission had therefore only one question to resolve—that of determining what are the most simple and sure methods of applying these principles in the exceptional case with which it has to deal.

After having deliberated in several sittings, the Commission resolved on one system which it submitted to the approbation of the Academy. We will endeavour first to give a general idea of it, after that we will enter into the details of execution.

General Arrangements.

The general arrangements refer to the three following points:

Firstly. We will begin by erecting with iron about three-quarters of an inch square, a conductor which shall dominate without interruption over the roofs of all the buildings it has to protect. When one or several pavilions occur in the course of the same roof, the conductor is raised in order to gain the summit of the pavilion, and then descends on the other side in order to resume its route.

We will call this great conductor the *circuit of the roofs*, as its form and various curves are in some measure modelled upon those of the roofs; it runs over them all without exception, and it will be found thus to have several branches, particularly in the new buildings, where several roofs rise parallel and perpendicular to the great roofs of the Quay and the Rue de Rivoli.

This circuit will have besides several branches much shorter, because it will have to be put in good connection with all the pipes, gutters, and great metallic surfaces which are found on the roof.

Secondly. The circuit of the roofs will be put in direct communication with the sheets of water of the wells which have a permanent supply of water. On this account there must be chosen suitable points for sinking ten or twelve wells, which will each

receive a descending conductor soldered to the circuit of the roofs. These descending conductors arrive at the water of the wells without any unnecessary windings.

It will be seen that by these arrangements all the metallic masses of the roofs communicate with the subterranean sheet of water.

Thirdly. The terminal rod of every conductor must be put in perfect connection with the surface of the roof. We will explain further on in the details of construction how these connections should be made.

Such is the abstract of the system proposed by the Commission.

In order that the system may be rendered easier of comprehension, and, above all, that it may be put into practice with all the care it demands, we give in the following paragraphs the relative explanations of the various methods of execution.

Erection of the Circuit of the Roofs.

The circuit of the roofs is composed of iron bars about three-quarters of an inch square and from thirteen to sixteen feet long. These bars are joined in this manner:—the ends of the bars are laid side by side and overlapping each by about six inches; they are then carefully soldered with good pewter solder and fastened together by two bolts.

When there is occasion to fix to the principal line of the circuit of the roofs a perpendicular branch, the junction must be made in this manner:—the new branch is terminated in the form of a T, of which the cross-bar is placed above the principal line of the circuit, where it is fastened by two bolts and soldered in the ordinary manner, whilst the stem of the T is prolonged to constitute the branch.

In certain cases the circuit of the roofs would rest immediately upon the roof. However, as it is important that these points and solders shall not be damaged in any way, either by the repairs of the roof or by other causes, it is probable that in general it will be necessary to sustain it at a certain height by means of supports suitably distant from each other. These supports would vary, following the form and disposition of the roofs themselves. Sometimes it will be necessary to have recourse to fixed supports; then they should be forked in order to prevent lateral displacements of too great an extent; at the same time they will permit the requisite expansion. At other times they could be limited to simple rollers of cast iron of six or seven pounds' weight, simply placed upon the roof and bearing upon their upper ends an opening intended for the reception of the circuit of the roofs.

The Compensation of the Expansion.—In a variation of tem-

perature of eighty degrees centigrade the expansion of the iron is about one thousandth part of a yard for one yard. Now in the climate of Paris the variations of the temperature of the circuit of the roofs would be about eighty degrees centigrade; thus every hundred yards' length of circuit may be elongated some four inches in passing from extreme cold to extreme heat and *vice versâ.*

It results from this that in those cases where the circuit of the roofs would have a great length in a straight line, it might be necessary to introduce in such places a compensator in order to counteract the play of expansion and contraction which would tend to compromise the adjustments of the apparatus.

In these circumstances, which occur but rarely and of which the architect is the best judge, we propose the employment of a compensator composed of a band of red copper three-quarters of an inch in breadth, two inches thick, and twenty-seven inches long. The extremities of this band of copper overlap each end of the two lengths of the circuit of the roofs by six inches and are fastened to them by strong solder. A piece of iron of the same section as the circuit of the roofs and also six inches long is placed over the ends of the copper and the whole is firmly bolted together. The band of copper is bent to the form of a semi-circle and opposes but a feeble resistance to an inflection a little greater or a little less. It is apparent that by this means the ends of the two lengths of the circuit of the roofs approach each other more or less according to the state of the temperature, and it is at this point that the effects of heat and cold are concentrated.

Let us suppose that for the play of expansion an interval of six inches had been preserved between the ends of the two lengths, the temperature at the time being, for example, 20° centigrade.

According as the temperature rises and proceeds more and more to its maximum of 60° above zero, the expansion causes the extremities of the ends of the lengths of the circuit of the roof to approach each other in such a manner that at the maximum of heat the interval is reduced to four inches and the compensator attains its maximum of closure.

On the other hand, the increase of cold below the mean 20° centigrade drives the ends of the two lengths of the circuit of the roofs more and more away from each other, and the interval increases until at the maximum of cold it reaches eight inches and the compensator attains its maximum of action.

If it should happen that the compensator should be exposed to accidental shocks or damage, it would be easy to find means of protecting it.

Pipes and other metallic Surfaces of the Roofing.—In both

the Louvre and the Tuileries the leaden pipes are adjusted with so much care that it is permissible to consider them as forming one continuous whole; as this is the case it will be sufficient to establish, at certain intervals, good connections between the pipes and the circuit of the roofs.

These connections could be made either with plates of sheet iron or any other form of flat iron of which the section must be at least five-sixteenths of an inch square. It is important to remember this necessary condition—that the soldering at the two points of connection, that is, on the leaden pipe and the circuit of the roof, should have from eight to ten inches square of superficial extent.

As to the other large metallic surfaces of the roofing, it will be necessary to render all the parts of it jointly responsible among themselves by uniting them, if need be, with bands of sheet iron soldered one piece to another; these precautions taken they must be connected metallically with the circuit of the roof, or if it is found to be more convenient, they may be metallically connected with the pipes since these last are directly united to the circuit of the roofs.

Connection of the Circuit of the Roofs with the Soil.

After what we have said of the circuit of the roofs, of its construction, and above all of its metallic continuity, one understands that the whole does not yet constitute a lightning conductor.

What is it that it wants for that? A very little thing, a very important one—it only wants a perfect connection with the soil.

In effect, let us admit that this connection is established. Let us admit that in taking some point of the circuit of the roof, there is soldered there the conductor which descends to the base of the edifice where it is bent horizontally in order to gain the opening of a well, and is there bent again so that it may reach the bottom and penetrate into the subterraneous sheet of water and communicate largely with it. In an instant the vast frame-work of the circuit is transformed into a lightning conductor; and it is worthy of remark that it becomes a universal conductor, protecting with the same efficiency the whole of the buildings the roofs of which it crosses.

Let us hasten to add that this deduction is more theoretical than practical, in this sense—that it is subordinate to certain conditions which are not always fulfilled. For instance, the circuit of the roofs would not protect any object more elevated than itself; the lightning when it exploded would, without doubt, strike such objects as chimneys, ornaments, &c. which would serve it in some measure as mediums whereby it would reach the circuit of the roofs. They would not however be the less broken and damaged in the passage of the

lightning. On the other hand, the least defect in the descending conductor would at once place in danger all the buildings.

Prudence commands us then to protect the circuit of the roofs with a sufficient number of terminal rods, more or less high, in order to prevent the ruin and damage of which we have spoken. This will be the subject of Paragraph IV.

Prudence also commands us not to limit the connection with the common reservoir, or the earth contact, to a single well nor to a single descending conductor. It is this last question which we now come to examine.

After the extension of the roofs and arrangements of the buildings of the Louvre and the Tuileries, we think it right that the number of wells should be increased to ten or twelve, to be suitably placed about the whole enclosure. We have also determined that the number of the descending conductors should be at least ten or twelve, so that each well should receive but one.

These wells, reserved exclusively for the service of the conductors, will be in the courts and near the façades. The position of each of them must be determined by the architect in such a manner that the descending conductor which should belong to it can reach it by a horizontal line of some yards in length.

Here is then the descending conductor; at its point of departure it is bolted and soldered to the circuit of the roofs in the manner described before (see preceding note). Then the stem of the T is bent, according to the conditions of the place, in order to arrive at the façade or angle of the building from whence it descends vertically as far as about eight inches beneath the pavement, it being fastened in its course in such a way as to sustain its weight and maintain it at a certain distance from the walls. The architect must advise on this point according to circumstances.

The descending conductor having arrived at the end of its vertical course is bent up parallel to the pavement and directed towards the centre of the well, where it arrives by a pipe prepared for this purpose resting thus from eight to ten inches below the soil. The pipe is then made fast with flags of iron or granite, of which the upper face is level with the pavement, and which has only to be lifted up in order to ascertain the condition of that part of the conductor.

At the end nearest the well, the conductor has fixed to it its last part, forming its indispensable complement; the length of this last part depends upon the depth of the well. It is fastened with solder and two bolts in a similar manner to the other joints already described. At its lowest extremity it has attached to it four 'roots,' which should, with the principal stem, be immersed in the water for a distance of two and a half feet at least. We may add that at the point where the

four 'roots' are bolted to the principal stem of the conductor, they are covered with a mass or knot of solder.

We will end this article by an important remark of which the architect should take account when there are any great repairs to be done to the building.

Two examples in form of questions, will serve to explain our ideas.

First Example.—When one of the lengths of iron which compose the circuit of the roofs is raised, producing thus a gap of about sixteen feet, is not the edifice by this exposed to danger?

No, it is not, because this gap is insignificant in respect to the distance of the tempest clouds. If the lightning should break, it would never strike in this small space of sixteen feet; it would necessarily fall upon the neighbouring part of the circuit of the roofs which would conduct it peaceably to the subterraneous sheet of water.

But this which is true of a gap of sixteen feet would cease to be true of a larger gap or break of from thirty to forty yards; then the corresponding part of the edifice would no longer be protected against the attacks of the lightning.

Second Example.—Let us consider now two successive descending conductors X and Y, separated the one from the other by an interval of two hundred and twenty yards. To the right of X one makes a gap or break of sixteen feet, and to the left of Y, a similar gap of the same length. Is the edifice exposed to any danger by the simultaneous existence of these two breaks in the circuit of the roofs?

Yes, the edifice is exposed to considerable danger. In effect the two hundred yards, more or less, of the circuit of the roofs which remain contained between the two small breaks of sixteen feet each, having no longer connection with the soil, have no more any efficiency against the lightning. The edifice is therefore without protection in the whole of the space which separates the two descending conductors, X and Y.

These short explanations will suffice to guide the architect in the arrangement of his work; he could bear them in mind in choosing the most favourable points for the sinking of the wells, and the establishment of the descending rods.

Terminal Rods and their Junction with the Circuit of the Roofs.

The terminal rod of a conductor is a quadrangular pyramid having at its base a square section of about two and a half inches, and at its summit a section of three-quarters of an inch; this summit is rounded and fitted with a screw-hole in order to receive a cylinder of red copper of three-quarters of an inch in diameter, and six inches

long. The upper part of this cylinder is diminished into a cone about one inch high, while the lower part is adjusted and fixed to the iron of the terminal rod with strong solder.

This cylinder of red copper ending in a cone is what is called the point of the conductor.

As to the height of the terminal rod, it is the interval comprised between its summit and the point at its base where it receives its conductor; all that is below this point is destined for the fixing of it very securely upon the framework of iron or wood, and cannot count as efficient height.

The height of the terminal rod can vary from sixteen to thirty-three feet according to circumstances, but in general the mean should be from twenty to twenty-eight feet.

It is necessary that the efficient length of the terminal rod should consist of one piece of metal.

In order to put a terminal rod in perfect connection with the subterranean sheet of water, it is sufficient to establish a connection with a point in the circuit of the roofs; for example, with the point which is the nearest to its base. This distance will always be short, and would very rarely extend to more than three or four yards.

We will call this very short conductor which unites metallically the terminal rod to the circuit of the roofs, the *conductor of the terminal rod*; it should always be made of iron having a square section of three-quarters of an inch.

It will be easily understood that there are only two important points in this conductor: its junction with the terminal rod and its junction with the circuit of the roofs.

The junction with the terminal rod must always be made by means of a screw and strong solder in the same manner we have described before.

The junction with the circuit of the roofs should be made as a rule by the method adopted for the joining of the perpendicular branches to the circuit; namely, by a T-shaped end fastened with bolts and solder.

However, it may happen that this general method presents certain inconveniences: for example, when the circuit of the roofs is prolonged in a straight line for any great length, so that it is necessary to have recourse to the compensator previously described, in order to prevent the troublesome effects of expansion. One can understand that the conductor of the terminal rod, drawn away by the direct or retrograde displacement of the circuit of the roofs, will tend to move entirely on account of its great rigidity; then the portion of the conductor which penetrates to the base of the terminal rod will be very much strained and eventually become liable to be broken itself by these repeated efforts.

In those points of the circuit of the roofs where the expansion requires very great amplitude, it will be necessary to give to the conductor of the terminal rod a certain suppleness which will permit it to obey the drawing away of the circuit of the roof without compromising its own continuity. This result can be obtained in different ways. We will limit ourselves here to show the following arrangement.

The iron of the conductor of the terminal rod is, as in ordinary cases, directed perpendicularly to the iron length of the circuit of the roof, but it need not reach there. It is cut off so as to leave an interval of from sixteen to twenty inches, destined to receive a band of red copper of which the free portion is undulated into the shape of a double S—§, whilst its extremities remain straight in order that they may be soldered, the one end to the iron of the conductor of the terminal rod, and the other to the circuit of the roofs. This band of copper should be three quarters of an inch in width and one fifth of an inch in thickness. Its straight ends should be each six inches long, and its free undulating portion should be about one and a half times the length of the distance between the circuit of the roofs and the end of the conductor of the terminal rod. It will then have a sufficient suppleness to obey such displacements of the surface as may arise from variation in the temperature.

It remains for us to give some indications as to the place which the terminal rods should occupy and their relative distances.

The first rule we establish in this respect is that of placing the terminal rods upon all the culminating points of the roof, such as pavilions, domes, belfries, &c. We will call these the principal terminal rods.

The second rule, less general and less precise than the first, is to determine, according to local circumstances, how many secondary terminal rods should be placed between two consecutive principal terminal rods.

Here are the considerations by means of which constructors of lightning conductors must be guided.

When in that interval one finds many objects having a notable height above the circuit of the roofs, as chimneys, ornaments, &c., the secondary terminal rods destined to protect these objects ought not to be distant from one another more than from twenty-seven to thirty-three yards.

When, on the contrary, it happens that in the interval which separates two principal terminal rods, the circuit of the roofs is not dominated by any object which is at any great height above it, one could, without inconvenience, place the secondary terminal rods at from fifty-four to sixty-six yards from one another.

We will end this 'Instruction,' recommending that at least once

a year it is necessary to examine and inspect the whole of the parts of the lightning conductors of all private and public buildings in order to ascertain whether they are in good preservation and whether their connection with each other and with the moist earth is perfect.

In all cases as regards public buildings, a report should be made on the state in which the lightning conductors are found, and the result of the inspection should be submitted to the competent authority.

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